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TRIALS OF THE DOPPLER MICROWAVE LANDING SYSTEM AT LONDON (GATWI--ETC(U)

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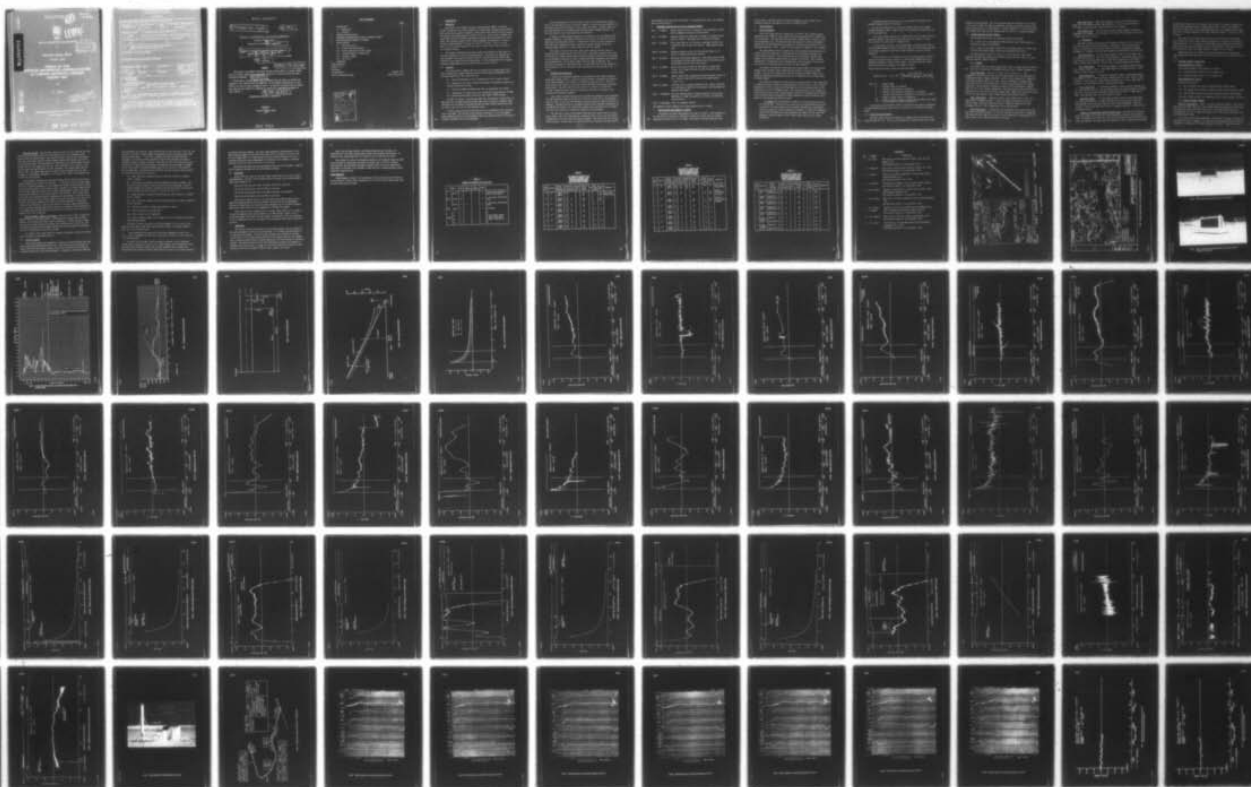
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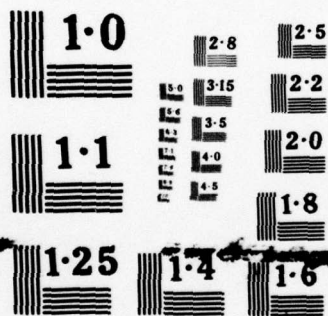
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Technical Report 78124

October 1978

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**TRIALS OF THE
DOPPLER MICROWAVE LANDING SYSTEM
AT LONDON (GATWICK) AIRPORT,
AUGUST 1977**

by

P.L. Gibson

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Technical Report 78124

Received for printing 10 October 1978

⑥ TRIALS OF THE DOPPLER MICROWAVE LANDING SYSTEM AT
LONDON (GATWICK) AIRPORT, AUGUST 1977

by

⑩ P. L. Gibson

SUMMARY

⑭ RAE-TR-78124

The trials of the Doppler Microwave Landing System (DMLS) at Gatwick formed part of a series conducted at operational airports to collect data for the ICAO evaluation programme.

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→ This Report contains typical data collected from the trials at Gatwick and analysis of the results shows that ^{the Doppler Microwave Landing System} DMLS met the performance requirements at this airport for line of sight propagation paths. No specific technique-related effects were seen, and the results are regarded as typical of C band MLS performance at this airport.

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LIST OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
1.1 Background	3
1.2 Overview	3
2 AIRPORT SITE DESCRIPTION	4
3 EQUIPMENT INSTALLATION AND TRIALS PROGRAMME SUMMARY	5
4 THE MULTIPATH ENVIRONMENT AT GATWICK	5
5 TRIALS RESULTS	6
5.1 Trials procedure	6
5.2 Ground based measurements	7
5.3 Tracked approach accuracy flights	8
5.4 Coverage flights - Flight UT23	10
5.5 Autoland flights	13
5.6 ILS checks	15
6 CONCLUSION	15
Acknowledgments	16
Tables 1 to 4	17
References	21
Illustrations	Figures 1-39
Report documentation page	inside back cover

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1 INTRODUCTION

1.1 Background

The trials of the Doppler Microwave Landing System (DMLS) at Gatwick Airport formed part of a series conducted at operational airports during 1977/78. This series was in specific response to ICAO State letter SD 23/1-77/127 in which the Council encouraged proposers of MLS to carry out real trials at typical airports prior to the All Weather Operations Divisional Meeting scheduled for April 1978. The airports visited in the trials programme were Brussels¹, Stansted, Gatwick, Kjevik (Norway)², Manchester³, Berne^{4,5}, Tehran⁶, John F. Kennedy (New York)⁷ and Dorval (Montreal)⁸, and each of these sites forms the subject of a separate report.

The primary information from these trials was submitted to ICAO prior to the April meeting in a series of working papers. This Report is intended as a more permanent and readily available record of the work and also looks at the results in more depth than the working paper. A full description of the Doppler Microwave Landing System used in these trials is given in Ref 9.

1.2 Overview

For these trials a Doppler MLS was co-located with an operational Cat II ILS on runway 08 at London (Gatwick) Airport during August and September 1977. The main objectives of the trials were to:

- (a) Confirm compatibility with a commissioned ILS at a major airport.
- (b) Demonstrate and record autoland performance using DMLS information as a direct substitute for ILS.
- (c) Extend the DMLS performance data base at operational air fields.
- (d) Demonstrate the speed and ease of installation and operation of DMLS at an international airport during the peak summer traffic season.

In order to provide a satisfactory basis for assessing the compatibility of DMLS with ILS, the DMLS elevation antenna was sited to provide a guidance datum equivalent to the nominal ILS glide path and the DMLS azimuth antenna was sited in front of and close to the ILS localiser array.

A flight inspection of the ILS was carried out immediately after installation of the DMLS. The results showed minimal disturbance to the ILS signals, which remained within Cat II performance limits and allowed normal ILS service to continue throughout the trials programme.

Fully instrumented and tracked flight trials of the DMLS facility showed that it was unaffected by any co-located elements of the ILS and that ICAO Cat III performance was easily obtainable on this runway from DMLS. Accurate angle outputs were obtained in all regions where adequate signal strength existed. At all other points a clear flag operation was obtained.

A number of fully automatic landings were carried out on both DMLS and ILS guidance facilities. The DMLS autolands were the first to be carried out at an operational international airport. A significant feature of these autolands is that they were accomplished using a very basic simplex autoland system and unsmoothed DMLS signals as a direct substitute for ILS signals.

The conduct of this trial was a joint effort between the CAA, RAE and Plessey with CAA organising the site facilities, ILS flight inspection and tracking facilities, Plessey supervising the ground equipment installation and setting up, and RAE RN2 conducting the actual flight measurement programme, data analysis and interpretation. The autoland flight tests were made by RAE FS2. The excellent cooperation of the Gatwick ATC at a peak traffic period and during the ATC Assistants' work to rule made a major contribution to the success of the trials.

2 AIRPORT SITE DESCRIPTION

A copy of the Instrument Approach and Landing Chart for London (Gatwick) Runway 08 is shown in Fig 1. A plan of Gatwick Airport identifying the position of the DMLS equipment with respect to runway 08 is shown in Fig 2. This also shows the position relative to the Cat II STAN 37/8 VHF ILS localiser and glide-path systems. Fig 3a&b show the azimuth array in relation to the VHF ILS localiser antenna and Fig 4 gives an overview of the site in relation to the terminal and maintenance hangars.

Fig 5 shows the DMLS elevation with the STAN 38 glidepath in the background. The DMLS elevation system was sited 55 m (180 ft) in front of the UHF glidepath array in order to give the same threshold crossing height for DMLS and ILS (50 ft nominal). The small profile of the DMLS elevation array minimised disturbance of the VHF/UHF ILS signals; ILS calibration flights after installation of the DMLS confirmed that there was no measurable change in ILS performance.

The terrain in front of both DMLS arrays was level ground covered in short grass, which, under the prevailing wet conditions, gave a near unity reflection coefficient at low (less than 3°) elevation angles. The terrain off the airfield includes gently rising ground; the horizon profiles as measured from the azimuth

and elevation sites are given in Fig 6a&b. The height profile under the approach path is given in Fig 7.

3 EQUIPMENT INSTALLATION AND TRIALS PROGRAMME SUMMARY

- | | | |
|--------|-------------|--|
| Day 1 | 17 August | Azimuth system arrived at Gatwick in late afternoon, installation commenced on pre-laid concrete bases. |
| Day 2 | 18 August | Azimuth installation completed overnight to minimise disturbance to traffic. ILS taken out of service for checks. |
| Day 3 | 19 August | CAFU flight check of ILS localiser confirmed no effect due to DMLS and ILS put back into service. DMLS azimuth runway runs. |
| *Day 4 | 22 August | Elevation system arrived, 08 ILS glidepath taken out of service and DMLS installation started. |
| Day 5 | 23 August | Elevation installation completed. CAFU flight check of UHF ILS glidepath confirmed performance within specification and the glidepath was put back into service. |
| Day 6 | 24 August | Radial and orbital flights by RAE Andover, Flight UT23, 7 runs. This flight was made at night during the quiet traffic period. |
| Day 7 | 25 August | Andover flight UT24 tracking the elevation system, 8 runs in all. Andover Flight UT25 tracking the azimuth system, 7 runs in all. |
| *Day 8 | 31 August | Autoland trials by Flight Systems HS 748. Flight consisted of 5 autolands on DMLS and 2 autolands on ILS recording both DMLS and ILS signals. |
| Day 9 | 1 September | Autoland demonstration by Flight Systems HS 748 recording DMLS only as flight was against the traffic and therefore 08 ILS was off. |
| Day 10 | 2 September | Start of equipment removal. |

*No weekend or Public Holiday test flying permitted due to traffic.

4 THE MULTIPATH ENVIRONMENT AT GATWICK

No specific multipath measurements were made at Gatwick. There appeared to be very little in the way of reflective surfaces and, apart from the obvious shadowing, detailed later in the report, the airport buildings apparently had

little effect. The main source of reflected signals was the terrain on the extended centreline and again this effect is detailed later.

5 TRIALS RESULTS

5.1 Trials procedure

In all 33 flight runs were carried out, of which 7 were tracked azimuth approaches (ILS or DMLS); 7 were tracked elevation approaches (ILS or DMLS) and 7 were autolands. The remainder were untracked coverage orbits, radials or data link calibration runs. The azimuth system was operated in both 54-wavelength aperture and 27-wavelength aperture modes; the elevation was operated with a 54-wavelength aperture. Table 1 shows the total number of flights in each category.

The basic DMLS accuracy was measured by the Telecroscope optical-infra-red tracker, which was operated by a CAFU ground crew following established ILS flight check procedures. This determines the aircraft angular position with respect to the selected approach path in azimuth or elevation. This tracking information is telemetered to the aircraft and is used to produce on-line error plots as well as being digitally recorded for later analysis⁹.

For azimuth tracking the Telecroscope was mounted behind the ILS localiser antenna on the extended runway centreline and raised to look over the DMLS azimuth. This put the tracking head about 62 m behind the DMLS azimuth array, making the tracking sensitivity about 2% low at threshold, with a correct match at larger ranges.

For elevation tracking the Telecroscope was mounted close to the runway edge (to keep the aircraft within the optical azimuth field of view of $+11^\circ$ at short ranges) and at such a distance from threshold as to put the optical head in the continuation of the 3° glidepath plane. The relative position of the tracker is shown in Fig 8a and the short range geometry relative to the DMLS and ILS systems in the vertical plane containing the runway centreline is shown in Fig 8b, from which the following points should be noted:

The nominal UHF ILS glidepath is taken as a 3° line from the base of the antenna mast. Whilst this is correct for far field matching, the path is distorted at short ranges, but no accurate information on performance within the range of runway threshold is available. It should be recognised that the UHF glidepath has conical geometry like DMLS, but the actual UHF antenna is normally phased to give a near linear path over the runway centreline.

The DMLS antenna was sited so as to put the ILS 3° reference line through the phase centre of the array.

As the Teleroscope has to be near the runway edge to get maximum tracking coverage at short ranges it must be low down and is also sited on the 3° reference line.

Due to the conical symmetry of a phased array and the offset from the runway the DMLS 3° code path, at short range over the runway, is hyperbolic and will lie above the 3° reference line.

On the Andover aircraft, the tracking lamp is situated about 2.29 m below the DMLS antenna and about 2.44 m in front, so that the path described by the lamp is generally below the 3° DMLS reference line until inside threshold.

The net result on a 3° approach is for an increasing positive error to show as the range decreases, which is to some extent compensated by the hyperbolic geometry of MLS at short ranges. The predicted error curves derived from the above geometry are shown in Fig 8c.

These curves are derived using the following formula:

$$\text{predicted error} = \theta_D - \tan^{-1} \left[\frac{\tan \theta_D \sqrt{(L + X)^2 + Y^2} + h_p - h_{at}}{(L + X)} \right],$$

where θ_D = Doppler angle
 X = aircraft range to threshold
 L = distance from tracker to threshold
 l = distance from elevation transmitter to threshold
 Y = distance from elevation transmitter to centreline (offset)
 h_p = height of phase centre of transmitter
 h_{at} = height difference between tracking lamp and MLS aerial added to the height of tracker from ground.

In presenting the elevation results no attempt has been made to compensate for these geometry effects which will be a function of the selected elevation angle.

5.2 Ground based measurements

The DMLS azimuth system was checked for alignment after installation by using the RAE test van. This van was equipped with a DMLS receiver and a basic

analogue recording system. The van was driven down the centreline of the runway at low speed to check the DMLS centreline and enabling errors due to any strong source of multipath to be investigated. By later analysis of UV records no multipath signals were found and the azimuth array was seen to be correctly aligned.

5.3 Tracked approach accuracy flights

The accuracy test results are presented in plots as follows:

- (a) A plot of the raw unfiltered DMLS receiver output (DMLS angle) as a function of range from threshold.
- (b) A plot of the angular difference (error angle) between the DMLS angle and the Telecroscope angle, plotted on an expanded angle scale.

Two flags appear on plots (a) and (b); the top flag is a 'data valid' indicator and shows any digital data dropouts, while the lower flag is a system flag and indicates system integrity.

5.3.1 Azimuth

The results from the tracked azimuth were taken on flight UT25 (see Table 2). Run 1 was used to calibrate the telemetry and Run 2 was a tracker alignment run.

Run 3 (Fig 9a-d). This was the first tracked azimuth run. Both transmitters were in the 54λ mode and the azimuth noise level was approximately 0.02° peak to peak at ranges less than 1 n mile. This increased to a maximum of 0.08° peak to peak at about 2.5 n mile, this is attributed to signals being reflected from the rising ground about 1 n mile from threshold on the extended centreline. The ground has a maximum up slope of 2.8° and subtends a maximum angle of 0.5° to the azimuth transmitter. The Telecroscope tracker suffered from drop-outs due to loss of lock on the aircraft lamp. Where this occurred the error traces were hand censored, Fig 9c shows typical Telecroscope dropouts.

Run 4 (Fig 10a,b). This run, as Run 3, was tracked from 5 n mile and is again quiet at ranges less than 1 n mile, but shows an increase in noise at greater ranges, peaking at about 2.5 n mile. Again the elevation was quiet throughout the run. Both transmitters were in the 54λ mode.

Run 5 (Fig 11a,b). During this run the azimuth was in the 27λ mode, and the noise was slightly greater, but did not increase in proportion to beamwidth. This again reached a peak at 2.5 n mile, but its amplitude is approximately 0.1° peak to peak. The tracker was locked at 5 n mile.

Run 6 (Fig 12a,b). Again the transmitter was in the 27λ mode and the noise level was somewhat greater than previously. At its worst it was about 0.12° peak to peak, generally twice as noisy as the 54λ mode.

Run 7 (Fig 13a,b). This run was the final tracked azimuth run and the transmitter was operated in its 54λ mode. The results are similar to Run 4 with a tracker lock at 4.8 n mile.

5.3.2 Elevation

The UT24 tracked elevation runs are tabulated in Table 3. Run 1 was used for data link calibration and setting up. During Run 2 the Telecroscope was found to be operating in the reverse sense and this was subsequently changed during Run 3. Therefore the first good results were obtained on the fourth run.

Run 4 (Fig 14a,b). 3° centreline approach. This run was tracked from 5 n mile with a good lock up to the runway threshold. The general noise level on the elevation system was 0.02° peak to peak with an increase to 0.04° peak to peak at 1220 m from threshold. This was due to residual ground reflections.

Run 5 (Fig 15a,b). 3° centreline approach. The DMLS performance during this run was similar to Run 4. Both DMLS signals were recorded from 5.5 n mile and the tracker locked at 3 n mile.

Run 6 (Fig 16a,b). 3° centreline approach. Again, the DMLS performance was similar to Run 4. The aircraft was tracked from 4.3 n mile. There is some evidence of small bends at ranges between threshold and 2 n mile, again this is attributed to reflections from the rising ground profile.

Run 7 (Fig 17a,b). 2° centreline approach. There was good tracking from 6.8 n mile during this run. The elevation guidance was good throughout, although the noise level was obviously greater, generally about 0.06° to 0.08° peak to peak. The long term bend structure looks very small.

Run 8 (Fig 18a,b). 4° centreline approach. This run was tracked from 4.3 n mile with evidence of tracker dropouts at 3.8 and 1.2 n mile (Fig 18b); both guidance signals were good with low noise levels throughout. There is evidence of small beam bends (0.04° pp) at a range of just over 1 n mile on the UV analogue record.

Summary of azimuth and elevation tracked runs. Generally the results are within the limits set by ICAO for a full-capability Microwave Landing System. These requirements are 0.076° (2 σ) noise for the elevation system and 0.054° (2 σ) noise for azimuth. The noise level on elevation for the 2° approach occasionally

exceeded these limits but in particular this run (Fig 17b) showed a higher noise content and long period bends at ranges greater than 1 n mile from threshold, which can be attributed to the rising ground profile on the approach path. This gave rise to ground reflections with small separation angles, 1° or less as shown on Fig 7.

The effect of the rising ground can also be seen on some of the azimuth plots, where the terrain causes spatially consistent or cyclic noise typical of a multipath effect. It is unlikely to be multipath from buildings in the terminal area as these all give out-of-beam codings, and being near to the azimuth transmitter they would give low Doppler shifts at ranges of 4 to 5 n mile.

Summarising, both the azimuth and elevation systems worked consistently well during the tracked approaches and the results are as to be expected from this site.

5.4 Coverage flights - Flight UT23

Data presentation - Radials

The coverage flights are presented in two plots:

- (a) Unfiltered DMLS elevation, ie 5 Hz sample rate
- (b) Unfiltered DMLS azimuth, ie 5 Hz sample rate

Data presentation - Orbits

Three plots are given:

- (a) The raw azimuth data plotted against nominal azimuth angle.
- (b) The azimuth data filtered to remove the basic rate of change of angle.
- (c) The raw DMLS elevation data plotted against nominal azimuth angle.

The actual flight profiles are summarised in Fig 19 and tabulated in Table 4.

5.4.1 Radial coverage flights

Run No. 1 (Fig 20a,b). 3000 ft altitude, centreline radial. This run was started at 37 n mile, there was a good azimuth signal and flag at 23 n mile and a good elevation signal and flag at 24 n mile. The azimuth system was quiet throughout the run and at ranges less than 9 n mile the noise was typically less than 0.03° peak to peak.

The elevation trace shows some sign of small bends at angles lower than 2° . This noise starts at a range of 13 n mile with a peak-to-peak value of 0.04° and increases to a maximum of 0.2° peak-to-peak at 16 n mile. (These values were

taken from the UV analogue record.) It then decreases again to a level of less than 0.1° peak-to-peak out to maximum range.

Run No. 2 (Fig 21a,b). 3000 ft altitude $+20^\circ$ (right) radial. During this run the azimuth system was consistently good from 9 n mile. There was some cyclic noise on the azimuth system at 10 n mile and some also at 13 n mile although of a slower period. This gave a maximum noise figure of 0.06° peak-to-peak.

The elevation system again gave good results although the noise figure rose to approximately 0.08° at angles lower than 3.5° .

Run No. 3 (Fig 22a,b). 3000 ft altitude, $+40^\circ$ (right) radial. There was some difficulty with the aircraft acquiring the correct azimuth angle during this run, as the azimuth system was programmed to flag at $\pm 40^\circ$. This can be seen on the azimuth plot and is identified as plus signs (+) when the aircraft exceeded the 40° limit. There were good elevation signals and a good flag at 12 n mile and the azimuth signal started slightly sooner. Generally the same effects on signal were seen as on the previous run.

Run No. 4 (Fig 23a,b). 3000 ft altitude, -20° (left) radial. The azimuth system was giving good usable guidance from 23 n mile with some cyclic error effects between 9 n mile and 13 n mile. This had a 3s period and a peak-to-peak level of 0.06° . This noise decreased in proportion to range.

The elevation signals were acquired at 22 n mile and, as previous runs have shown, were quiet down to an elevation angle of 3.5° when the noise level increased, peaking at 2.5° .

Run No. 5 (Fig 24a,b). 3000 ft altitude, -40° (left) radial. Again during this run the aircraft flew in and out of the 40° coverage and the flag on the azimuth trace is identified by plus signs to show this. The azimuth signals were good from 27 n mile. The elevation was good from 26.5 n mile with some bends and noise at low angles, generally as described previously.

Conclusion: Coverage radials. The coverage radials show that the system was functioning throughout the azimuth range ($+40^\circ$ to -40°). Generally speaking they are quiet and show good quality guidance signals. There is, however, some indication of a multipath effect at low elevation angles on the elevation traces and this again can be attributed to the rising ground on the approach paths.

The two outer azimuth traces, Fig 24(b) and 22(b) show the effect of the out of coverage flag, this is set inside the receiver to a predetermined limit which at Gatwick was $\pm 40^\circ$.

The range at which signals were acquired on the radials was directly related to the ground profiles as shown in Fig 6a&b. At 20 n mile and 3000 ft the aircraft is at an elevation angle of 1.4° from the azimuth transmitter and 1.6° from the elevation transmitter. This is why the signal on the positive 40° radial was acquired at about 12 n mile, and on the negative 40° radial at about 26 n mile. The negative side of the airfield was relatively clear of obstructions whilst the other side had fairly high buildings and tree line.

5.4.2 Orbital coverage flights

Run No. 6 Orbit 2500 ft altitude 20 n mile radius. Azimuth, Fig 25a&b and 6a Fig 25a&b show azimuth coverage and performance consistent with the profile plot 6a. The signal coverage is almost $\pm 40^{\circ}$, but is very noisy throughout; again we are effectively on the limit of coverage.

The noise level decreases on the centreline and is highest on the positive side. This will be due to shadowing and reflection of signals from the hangars starting at $+30^{\circ}$.

The loss of signal and flag at 0° is caused by the ground reflected signal nulling the real or wanted signal. The wanted signal was already very small and the receiver could not withstand this apparent small loss in the signal, and lost the function identity code (Fig 25a). The gap at $+20^{\circ}$ is probably due to shadowing by the church spire shown in Fig 6a.

Elevation, Fig 25c and 6b. This low altitude orbit brings the aircraft almost to the limit of coverage, at an elevation angle of 1.0° . Fig 25c shows elevation coverage and performance consistent with the profile plot 6b. Where there were no signals, a consistent flag was indicated at all times.

The signals appear fairly noisy although acceptable about centreline, but elsewhere in the coverage they are very intermittent due to severe shadowing as shown on the profile.

Run No. 7 Orbit 10000 ft flight level 20 n mile radius. Azimuth Fig 26a&b. The azimuth system was good throughout its coverage of $\pm 40^{\circ}$. The noise level was generally low and, looking at Fig 6a, the aircraft elevation angle (approximately 4.5°) took it well above the shadowing effects of any buildings or obstructions. The step which occurred at $+25^{\circ}$ was due to an increase in the angular rate of change, as the computer programme used to generate a pseudo reference angle assumes a constant angular rate of change an aircraft path change may appear as a step. The flags were good throughout the coverage again with a good off flag at $\pm 40^{\circ}$ and no false flags out of coverage.

Elevation Fig 25c. The aircraft receiver was set to 4.8° elevation for this run and as can be seen from Fig 6b there should be no direct shadowing apart from the UHF ILS monitor masts. The results, Fig 25c, confirm this, being generally very quiet apart from the extreme azimuth angles with slightly more noise on the positive side. This may have been reflections from the buildings or trees on this side of the runway (see Fig 6b). With reference to this figure, it can also be seen that the ILS monitor at 20° subtended a much higher angle than the mast at 35° ; the higher angle mast had little effect although there was some evidence of a small cyclic phenomena at $+20^{\circ}$ whilst the effect of the smaller mast at $+35^{\circ}$ was very evident.

This apparent contradictory situation arises from the nature of the interference generated by a 'thin' vertical pole. If the pole is of sufficient length that it is equally illuminated by all elements of the MLS elevation array relative to the elevation angle of the aircraft, then it appears as a second signal source with the same angle code as the direct signal and introduces little or no error. This condition applies to the monitor mast at $+20^{\circ}$ azimuth. On the other hand, if the pole is so positioned that illumination by the elements at the top of the MLS array relative to the elevation angle of the aircraft passes over the top of the pole, the second signal source formed by the pole appears as a shortened version of the MLS array. This has the effect of putting a phase discontinuity in the resultant received signal which cycles as a function of the difference in path lengths from the MLS array and the pole to the aircraft, giving rise to the typical error seen in Fig 26c.

Orbital flights : General conclusion. The low orbit at 2500 ft shows the absolute limits of the DMLS system. Although both the azimuth and elevation showed a lot of noise the system worked as expected. No false course or flags occurred and in both cases good guidance was available about centre line. The correlation between elevation angle profiles and received signal was extremely close for both azimuth and elevation systems.

The 10000 ft orbit shows good clean signals throughout coverage and clearly gives a guidance of requisite quality.

5.5 Autoland flights

Autoland performance was assessed by a series of coupled approach and landings in RAE Flight Systems HS 748 (Fig 27). This aircraft was not equipped to operate with the Telecroscope tracker, so that all relevant airborne data was recorded digitally for post flight analysis. In general, simultaneous DMLS and

ILS information was recorded. This aircraft used an SEP6 autopilot which had been modified to provide a single channel autoland facility with glide path extension and flare modes. It used radio altimeter for flare guidance and mode switching. The typical circuit pattern for the HS 748 indicating the modes of autopilot control is shown in Fig 28. Note that for this trial there was no use of inertial or body-derived acceleration information thus providing a stringent test of the quality of the DMLS signals which are fed direct to the autopilot with no smoothing. Autoland data was presented on eight parallel tracks showing the following parameters for each run:

- (a) DMLS unfiltered analogue elevation deviation scaled to a nominal $\pm 0.67^\circ = \pm 150\mu\text{A}$.
- (b) ILS unfiltered analogue elevation deviation scaled to $\pm 150\mu\text{A}$. Note that the recorded output of the ILS receiver had no smoothing. The frequency response was therefore limited by the ILS tone filter and rectifier circuits which were of the order of $\sim 3\text{ dB}$ at 8 Hz ie 0.02 s .
- (c) DMLS unfiltered analogue azimuth deviation output scaled to a nominal $\pm 1.8^\circ = \pm 150\mu\text{A}$.
- (d) ILS unfiltered analogue azimuth deviation scaled to $\pm 150\mu\text{A}$, bandwidth as for elevation.
- (e) Indicated airspeed covering the range 80 to 120 kn.
- (f) Pitch attitude in the range $\pm 10^\circ$.
- (g) Roll attitude in the range $\pm 20^\circ$.
- (h) Radio altimeter height in the range 0 to 150 ft, referred to the main undercarriage wheels.

The point of flare initiation at the 45 ft height, and one second timing marks are also shown in the upper and low marker traces, ie between channels 1 and 2 and 7 and 8 respectively.

All the approaches were made with a tail wind component of about 6 kn and a crosswind component of 6 kn and all approaches finished in a well defined flare and touchdown.

In particular, the DMLS elevation signals continued to give consistent results down to heights as low as 12 ft. These flights clearly demonstrate that the basic DMLS elevation signals give accurate guidance with a simple omnidirectional blade airborne antenna right down to the point on the runway alongside

the ground elevation antenna. The short range hyperbolic characteristic of the DMLS elevation signal has in actual fact proved to be a benefit in terms of the use of a simple AFCS as it tends towards the flare profile required, but with different elevation array displacements at different sites leading to different profiles it adds yet another variable to the system.

The plots from these runs are presented as Figs 29 to 35 inclusive. Figs 32 and 34 being ILS autolands and the others DMLS autolands.

5.6 ILS Checks

These checks were made by the CAFU flight inspection HS 748 using standard instrumentation. The four plots presented show the system error plotted against range from threshold for:

Fig 36 the ILS localiser before the DMLS azimuth was installed,

Fig 37 the ILS localiser with the DMLS in position,

Fig 38 the ILS glidepath before the DMLS elevation was installed,

Fig 39 the ILS glidepath with the DMLS in position.

There was no obvious effect on the ILS system after DMLS installation as shown by comparing Figs 36 and 37 (localiser) and Figs 38 and 39 (glidepath). This was as expected as the relatively small physical size of the DMLS equipment should have little effect on the propagation of VHF/UHF ILS signals.

These results can be compared with the tracked DMLS results but in doing so it must be remembered that the bandwidth of the DMLS guidance signal is 0 to 2.5 Hz (5 Hz sample rate) whilst the ILS signals are smoothed with a time constant of 0.5 s (bandwidth 0.3 Hz) in accordance with recommended ICAO flight calibration practice.

6 CONCLUSION

The results from the trials gave an interesting insight into the effects of microwave propagation (5 GHz) on the performance of the Doppler Landing System at a relatively clean sight. At first no real problems were expected at Gatwick, but the effect of the rising ground profile on the approach path was very significant, giving increased noise on azimuth approaches, and oscillations on elevation radials. The system did not meet the ICAO long-range low-angle requirements of guidance at 20 n mile down to a slope of 1:50 from touchdown as evidenced by the results on the orbit at height of 2500 ft and a range of 20 n mile.

Apart from coverage effects, the DMLS performance was very good, its installation on this busy international airport went smoothly and quickly. No effects on the conventional ILS, with which it was co-located, were seen.

This airport in terms of surrounding terrain is not untypical (many are much worse eg Berne in Switzerland and Kjevik in Norway) and it must be accepted, therefore, that the long-range low-angle coverage called for in the operational requirement is unlikely to be obtained at many sites by a landing guidance system using this frequency band.

Acknowledgments

Acknowledgment is made to the assistance given by the BAA and CAA staff at Gatwick airport, without whose co-operation at a difficult time, these tests could not have been carried through.

Table 1

SUMMARY OF GATWICK TRIALS FLIGHTS

Flight	Run	AZ tracked	EL tracked	Other		
RN2	UT 23	7	-	-	7	Azimuth and elevation orbits and radials
	UT 24	8	-	5	3	3 untracked calibration runs
	UT 25	7	5	-	2	2 untracked calibration runs
FS2	155/11	7	-	-	7	Autolands
CAFU	17	1	1	-		} ILS flight checks before and after DMLS installation
	18	1	1	-		
	24	1	-	1		
	25	1	-	1		

Table 2

LOG DETAILS FLIGHT UT 25
GATWICK 25 AUGUST 1977
AIRCRAFT ANDOVER XS646
OMNI AIRBORNE ANTENNA

Run No.	Profile	Transmitter systems	Airborne records			Telecroscope track	RX	Raw data plot	Error plot	Comments
			UV	Digital	XY					
1	3°	AZ54λ EL54λ	✓			No No			No No	Data link calibration
2	3°	AZ54λ EL54λ	✓ ✓	✓ ✓		No No			No No	
3	3°	AZ54λ EL54λ	✓ ✓	✓ ✓		✓ No		✓	✓	
4	3°	AZ54λ EL54λ	✓ ✓	✓ ✓		✓ No		✓	✓	
5	3°	AZ27λ EL54λ	✓ ✓	✓ ✓		✓ No		✓	✓	
6	3°	AZ27λ EL54λ	✓ ✓	✓ ✓		✓ No		✓	✓	
7	3°	AZ54λ EL54λ	✓ ✓	✓ ✓		✓ No		✓ ✓	✓ ✓	

Table 3

LOG DETAILS FLIGHT UT24
 GATWICK 25 AUGUST 1977
 AIRCRAFT ANDOVER XS646
 OMNI AIRBORNE ANTENNA

Run No.	Profile	Transmitter systems	Airborne records			Telecroscope track	RX	Raw data plot	Error plots	Comments
			UV	Digital	XY					
1	3°	AZ54 λ EL54 λ	No No	No No	No No	No No		No	No	Data link calibration
2	3°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	No No	Reverse sense telecroscope
3	3°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No No		✓ ✓	No No	Telecroscope sense changed
4	3°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	✓	
5	3°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	✓	
6	3°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	✓	
7	2°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	✓	
8	4°	AZ54 λ EL54 λ	✓ ✓	✓ ✓		No ✓		✓ ✓	✓	

Table 4

LOG DETAILS FLIGHT UT24
 GATWICK 24 AUGUST 1977
 AIRCRAFT ANDOVER XS646
 OMNI AIRBORNE ANTENNA

Run No.	Profile	Transmitter systems	Airborne records			Telecroscope track	RX	Raw data plots	Error plots	Comments
			UV	Digital	XY					
1	3000 ft on	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
2	3000 ft 20° R	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
3	3000 ft 40° R	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
4	3000 ft 20° L	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
5	3000 ft 40° L	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
6	Orbit 2500 ft 20 nm	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	
7	Orbit 10000ft 20 nm	AZ54λ6 ⁺ 6 ⁻	✓	✓		No		✓	No	
		EL54λ20 ⁺ 20 ⁻	✓	✓		No		✓	No	

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<u>No.</u>	<u>Author</u>	<u>Title, etc</u>
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2	R. Matthews	MLS trials at Kristiansand (Kjevik), Norway 1977, 1978. RAE Technical Report to be published (1979)
3	D. Walker	Trials of the DMLS at Manchester International Airport October/November 1977. RAE Technical Report 78144 (1978)
4	R. Matthews	Performance assessment trials of DMLS at Berne Airport. RAE Technical Report to be published (1979)
5	R.B. Lumsden	Automatic landing trials at Berne (Belp) Airport using DMLS guidance December 1977 RAE Technical Report to be published (1979)
6	R.B. Lumsden	DMLS trials at Tehran (Mehrabad) Airport January/February 1978. RAE Technical Report to be published (1979)
7	P.L. Gibson D. Walker	Comparative trials of the DMLS and the TRSB MLS at the John F. Kennedy International Airport New York. RAE Technical Report to be published (1979)
8	R.B. Lumsden	DMLS trials at Montreal (Dorval) Airport April 1978. RAE Technical Report to be published (1979)
9	J.M. Jones	Contribution to the UK DMLS research and development programme 1974 to 1978. RAE Technical Report to be published (1979)

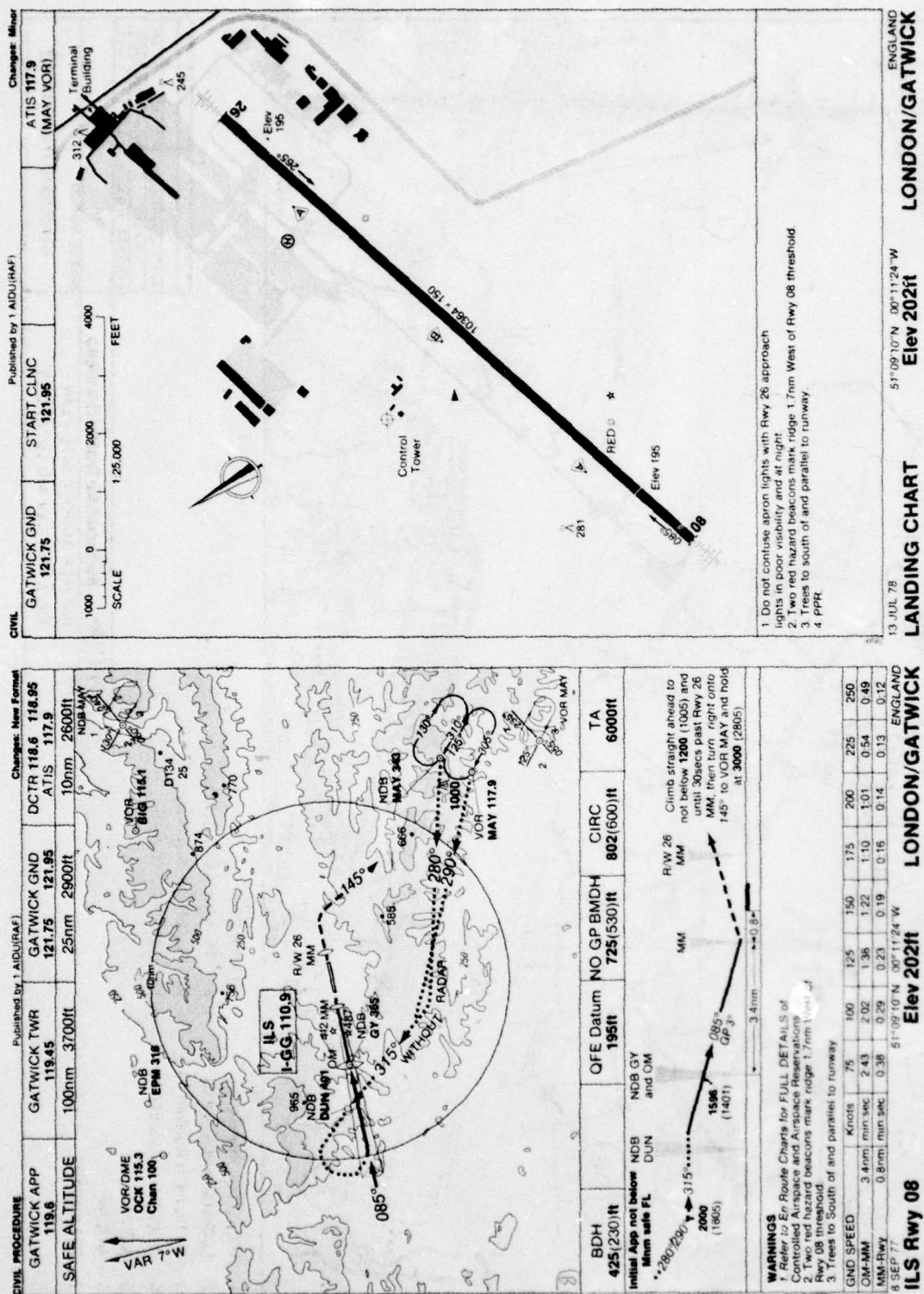


Fig 2

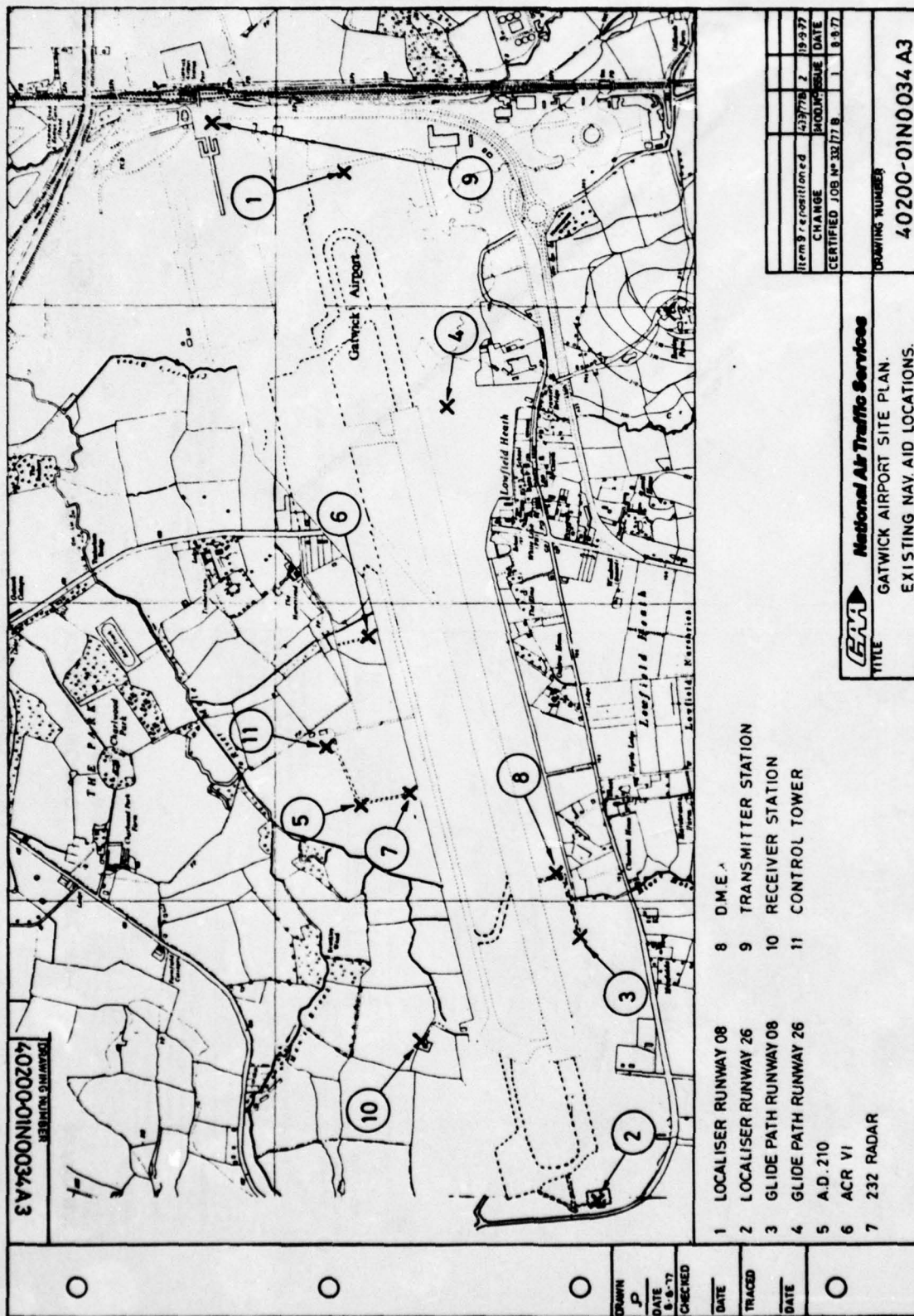


Fig 2 Gatwick airport site plan. Existing navigational aid locations

Fig 3a&b

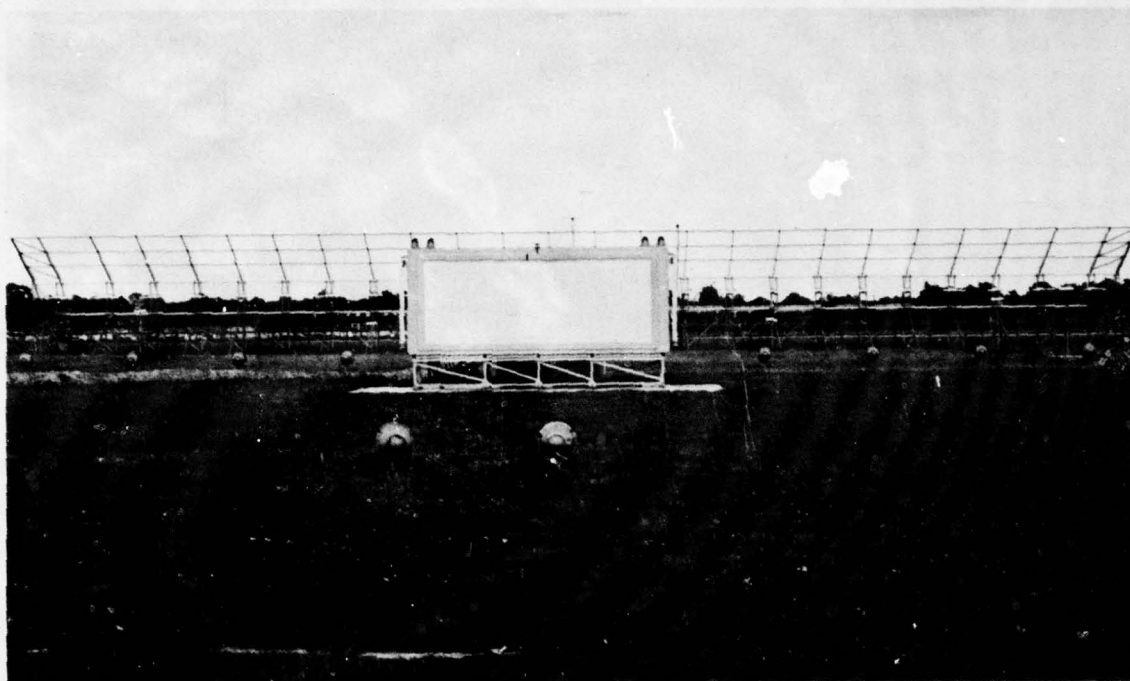


Fig 3a DMLS azimuth antenna sited in front of ILS localiser

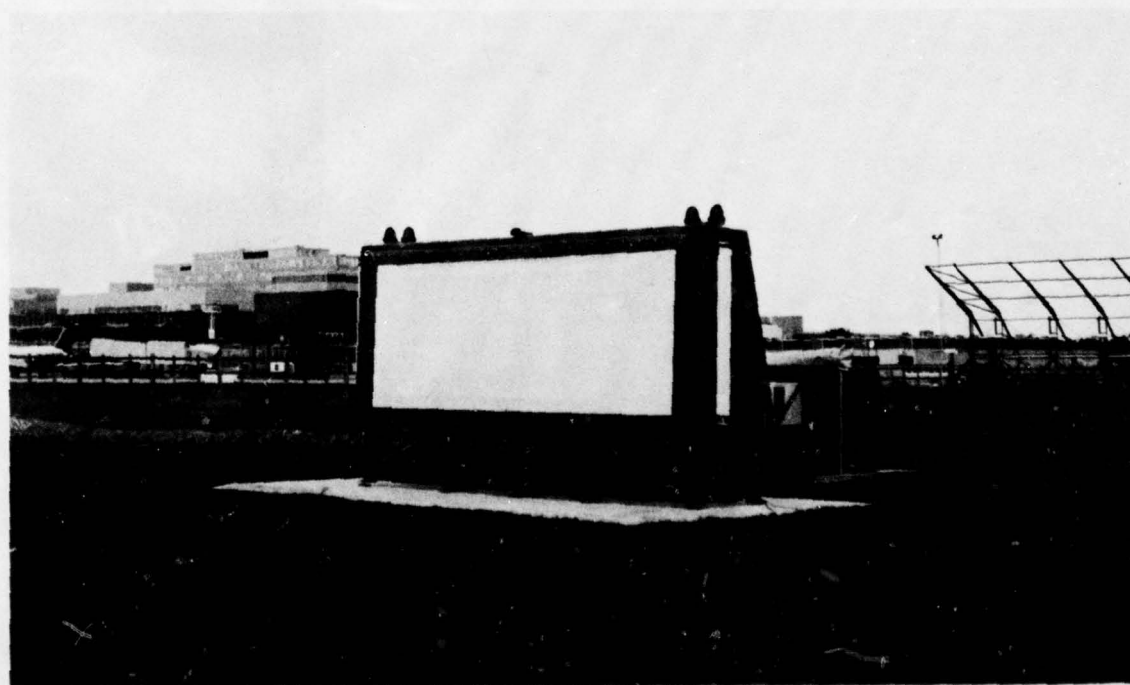


Fig 3b View of DMLS azimuth facility installed 30 metres in front of Category II ILS localiser

Figs 4&5



Fig 4 Overview of stop end of runway 08 showing Category II ILS and DMLS azimuth facility

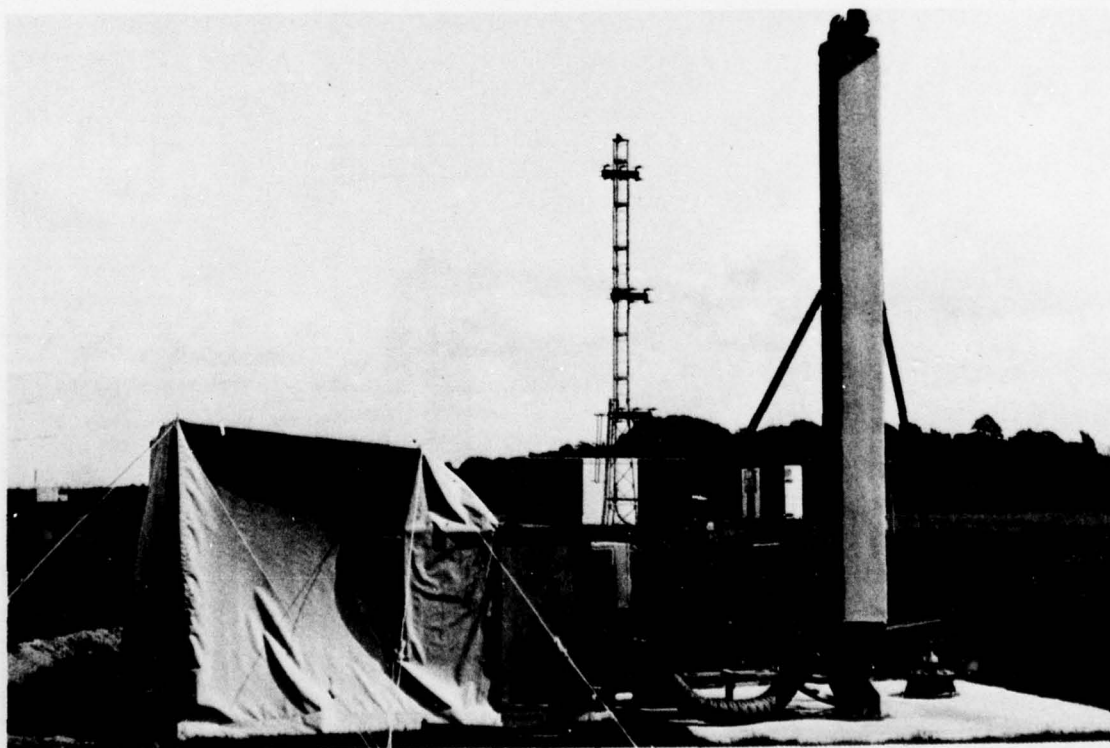
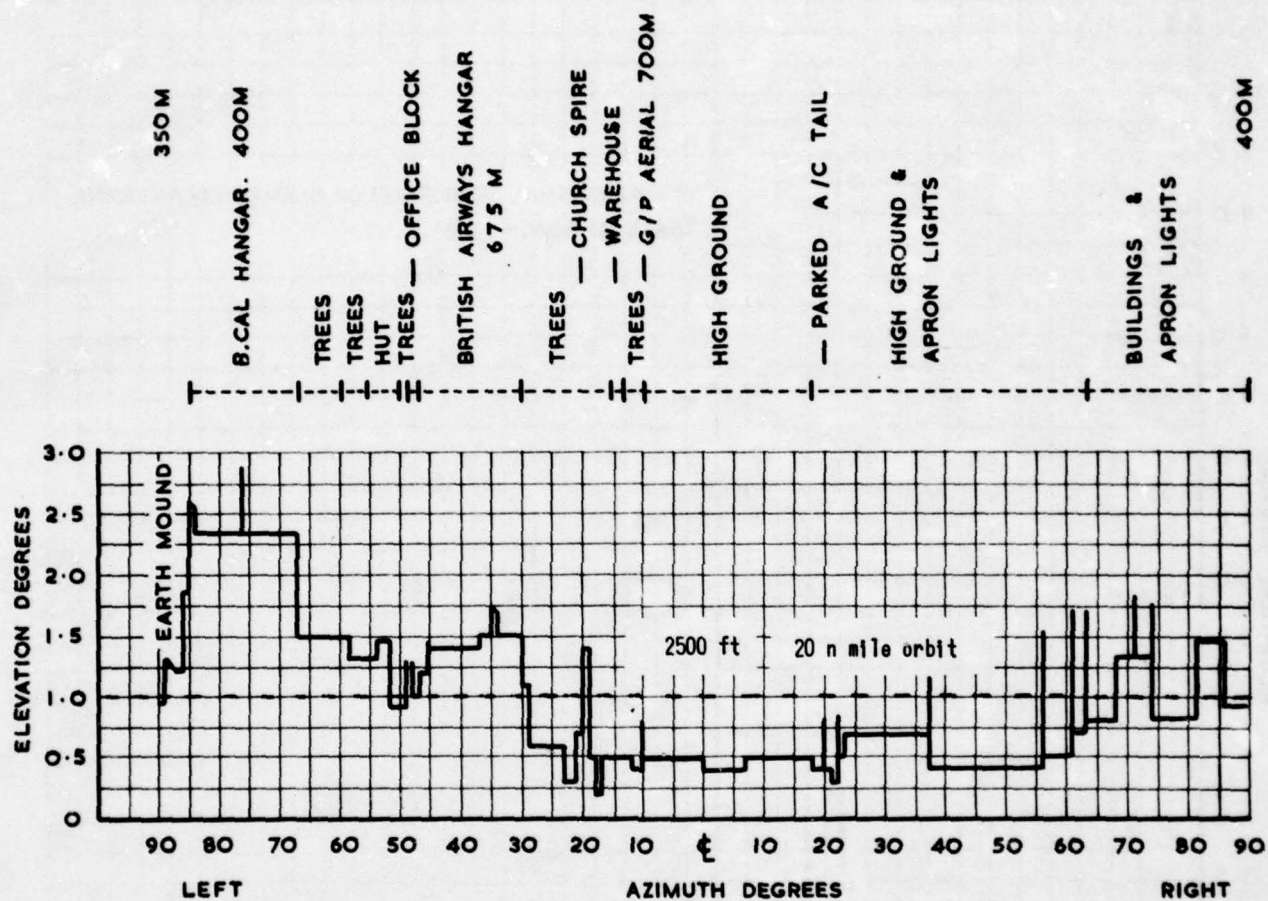


Fig 5 View of DMLS elevation facility installed 55 metres in front of Category II ILS glidepath

Fig 6a



0° = RUNWAY CENTRELINE and AZIMUTHAL BORESIGHT OF AZIMUTH ANTENNA
 Theodolite height = 1.42M

Fig 6a London (Gatwick) Airport, runway 08, DMLS azimuth site — horizon profile

Fig 6b

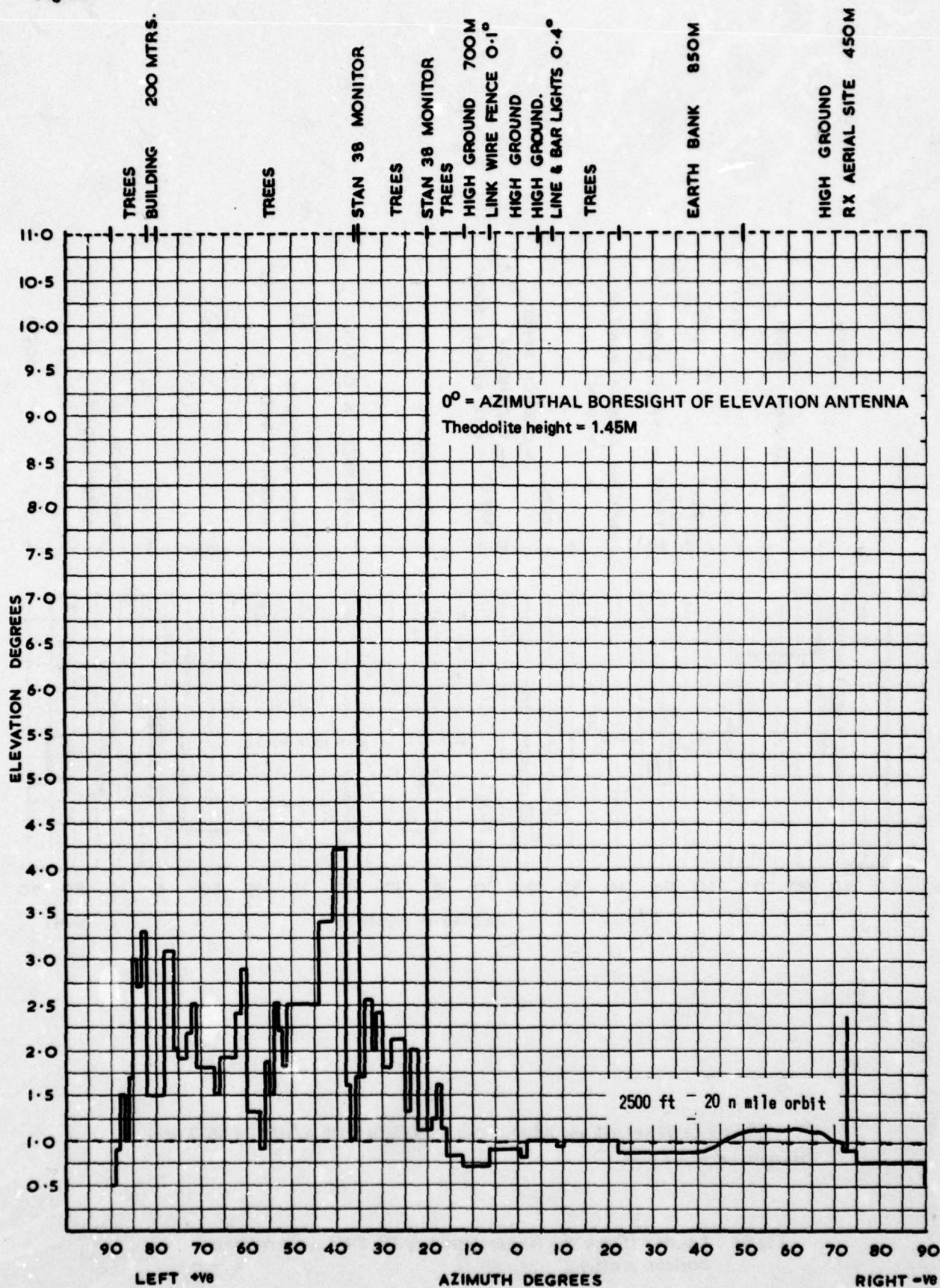
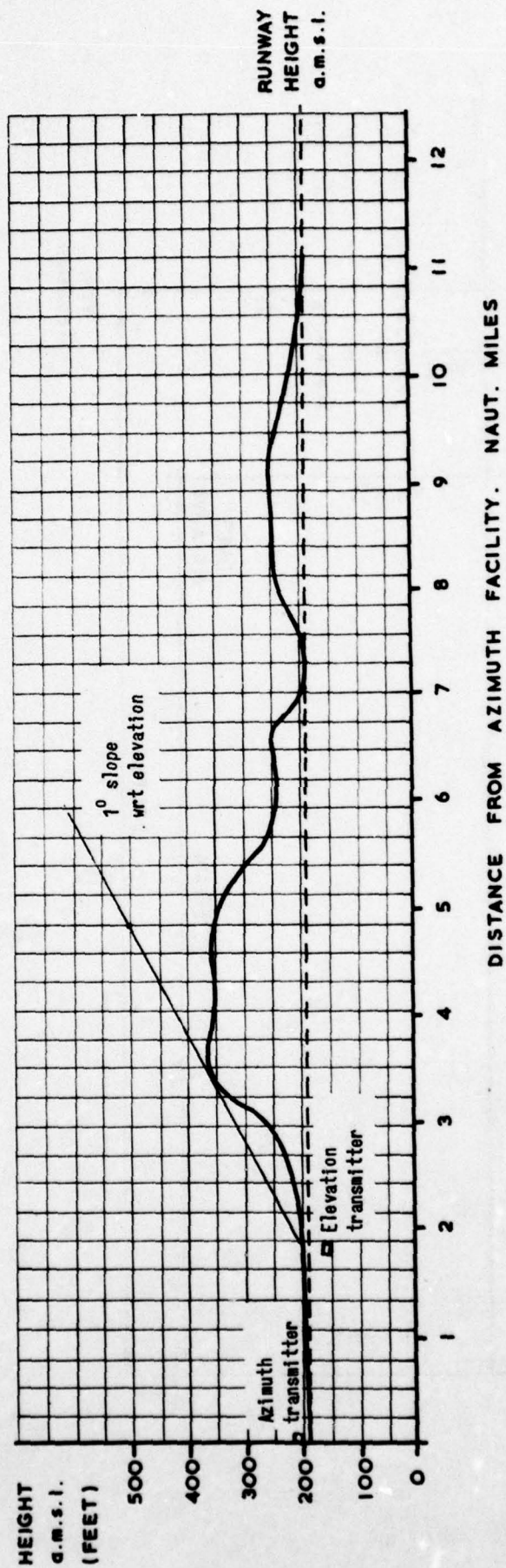


Fig 6b London (Gatwick) Airport, runway 08, DMLS elevation site — horizon profile



GATWICK 08.

Fig 7 Extended centre line ground profile

Fig 8a

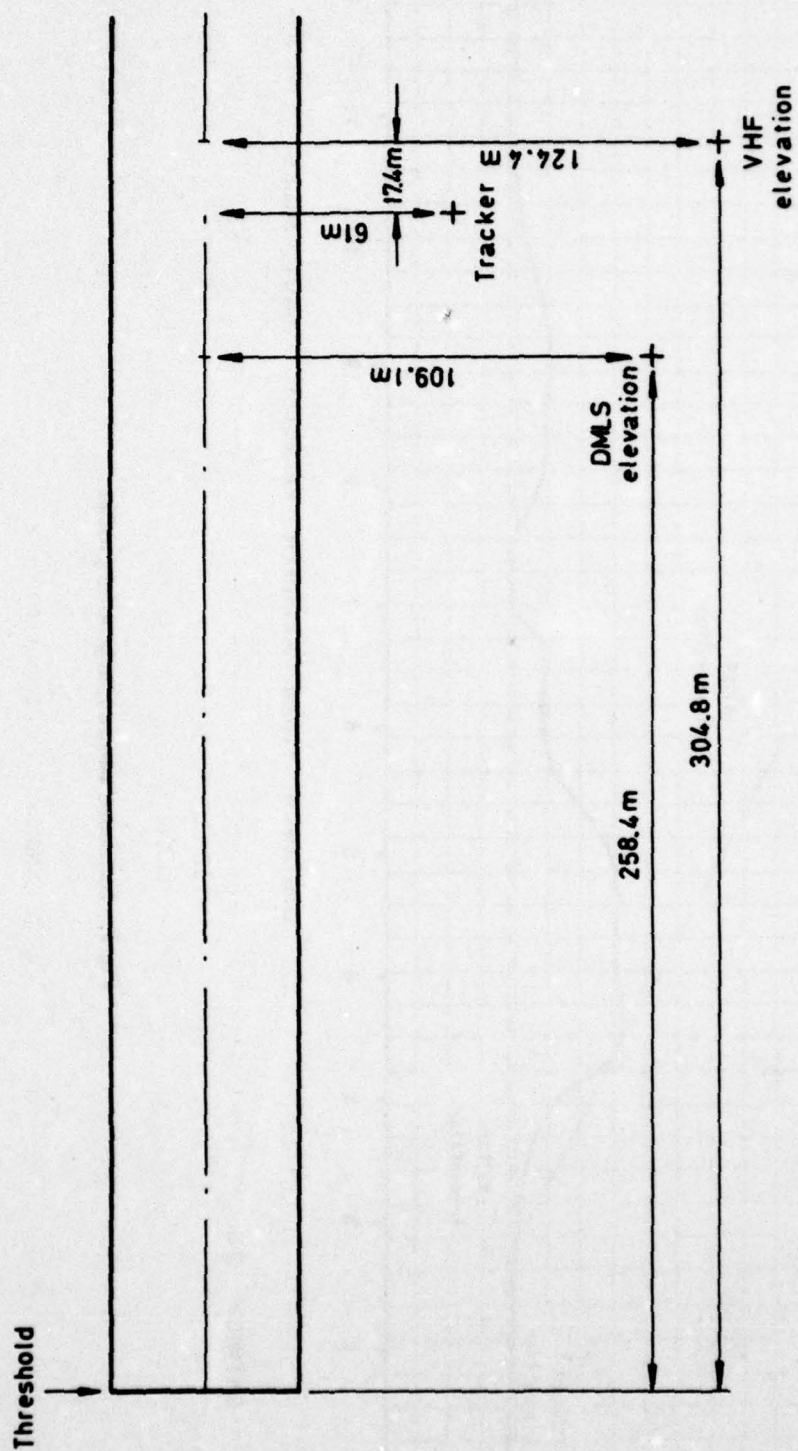


Fig 8a Plan of elevation siting

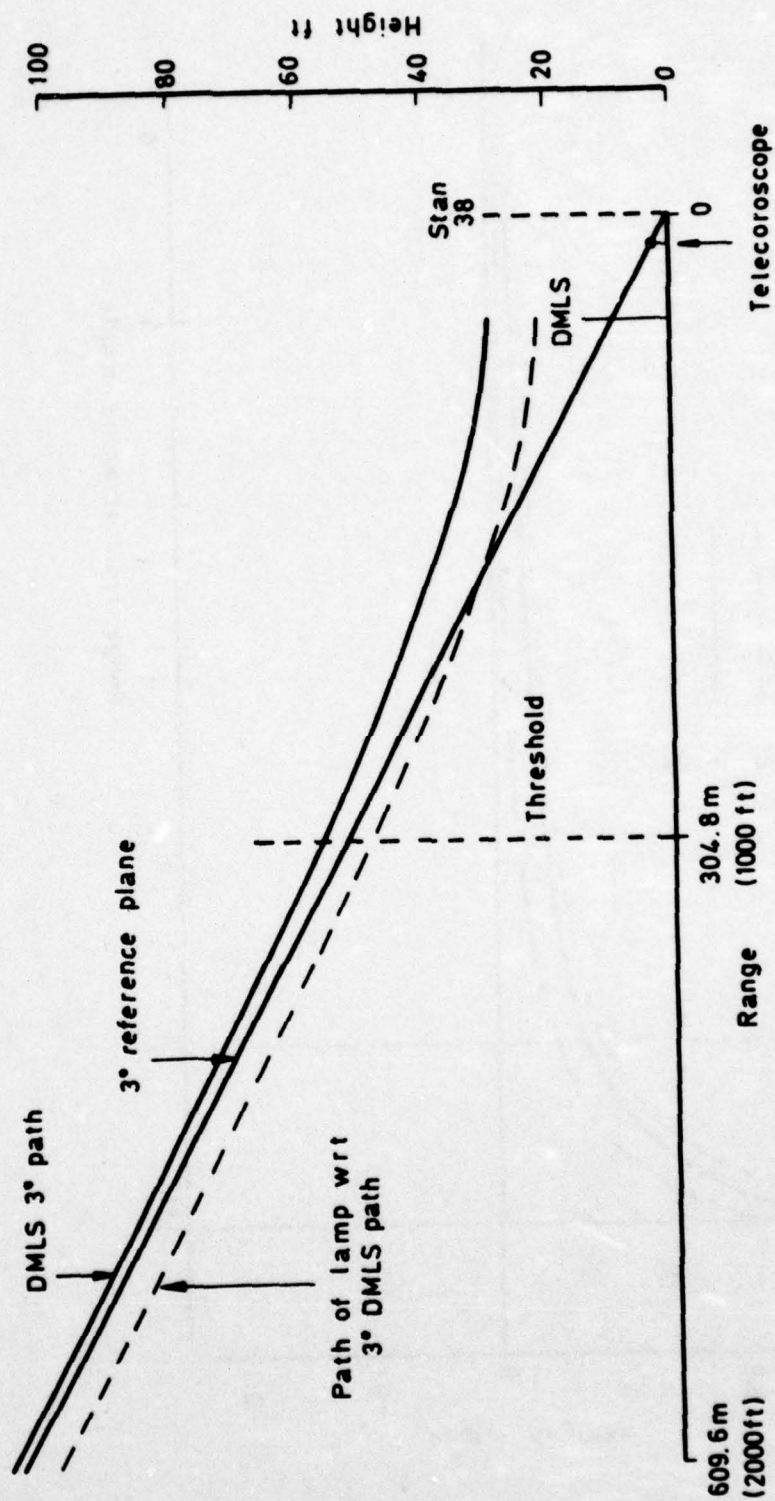


Fig 8b Short range elevation geometry

36

Fig 8c

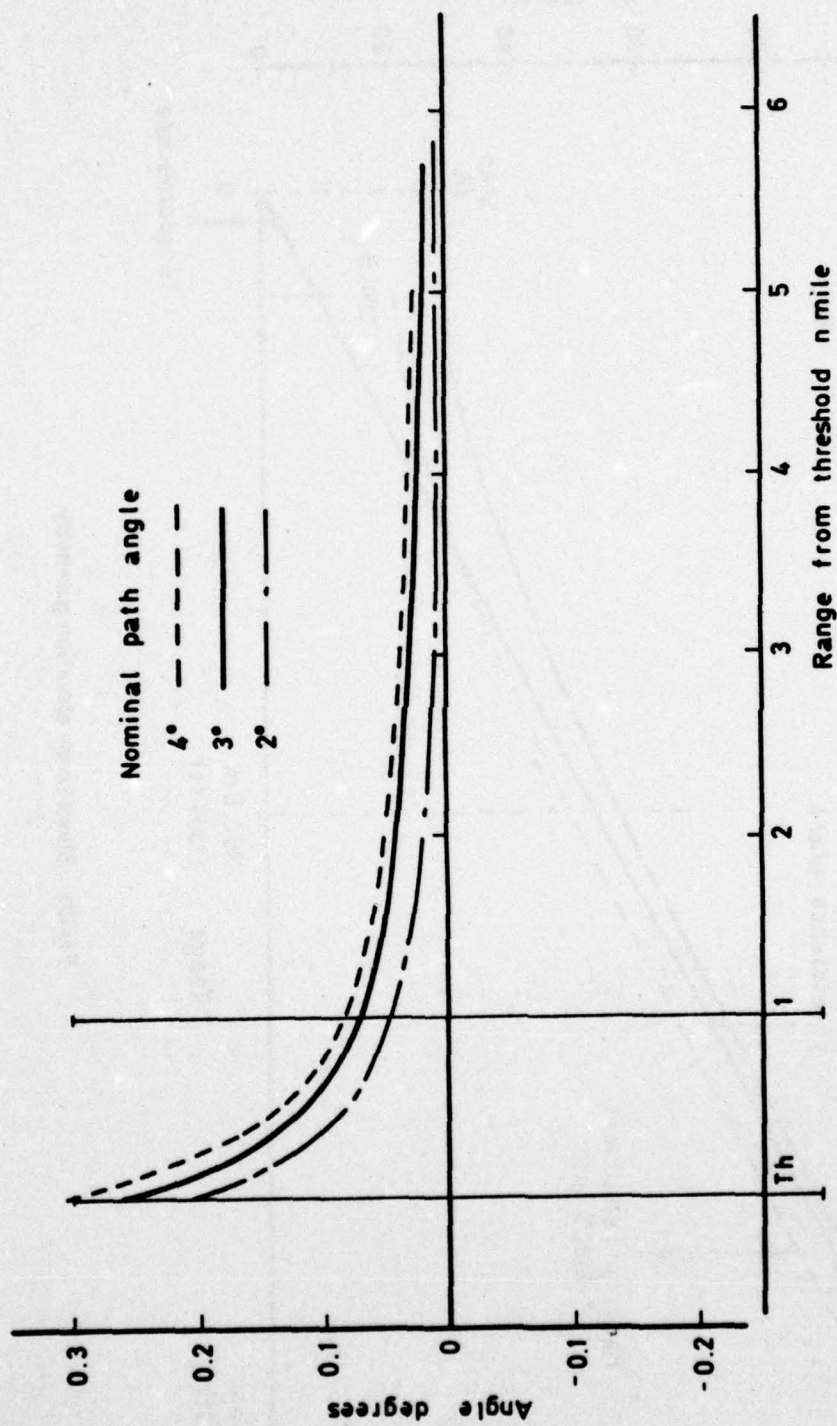


Fig 8c Error curves due to tracker geometry

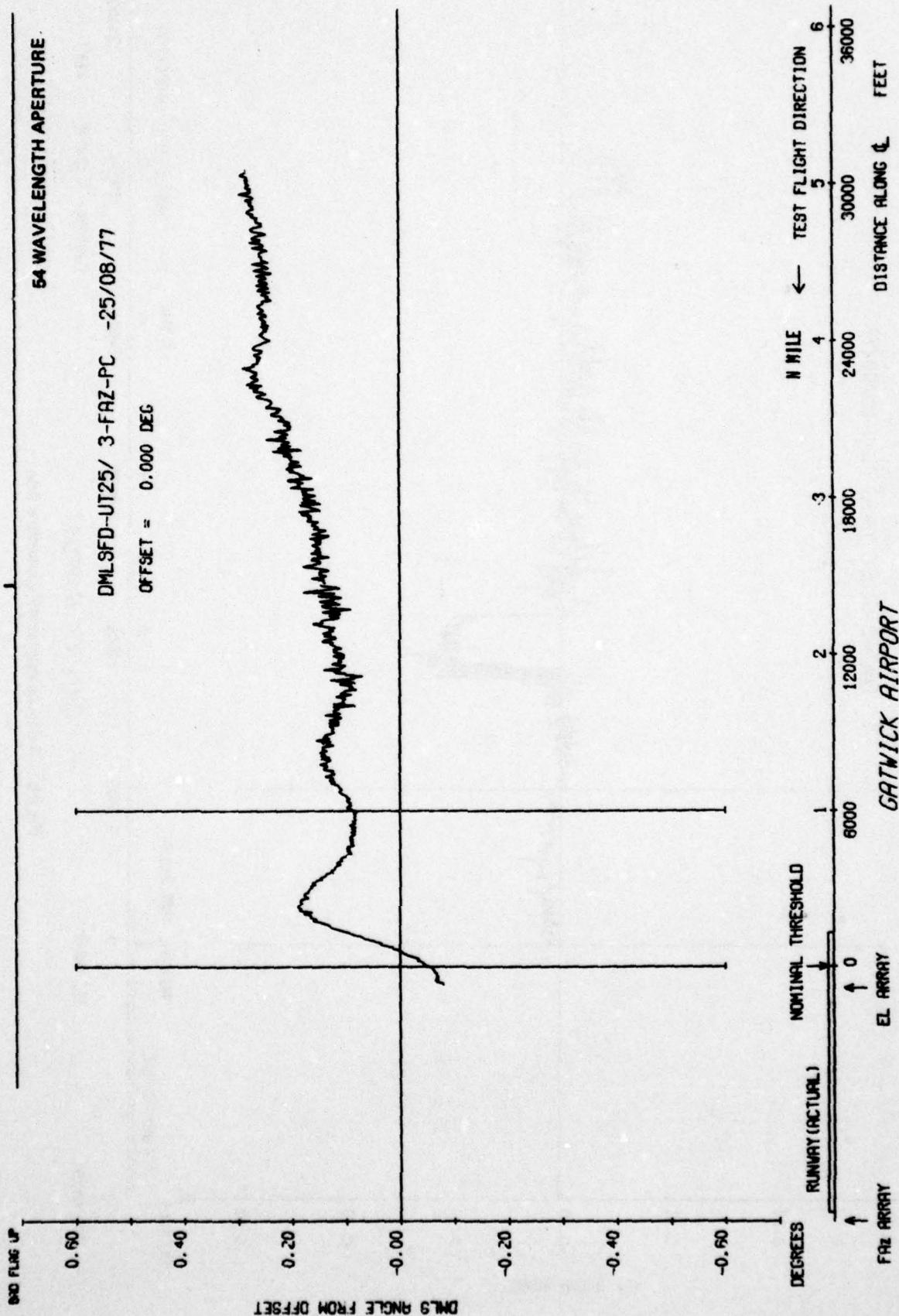


Fig 9a 3 degree approach on centre line

54 WAVELENGTH APERTURE

DMLSFD-UT25/ 3-FAZ-PC -25/08/77

OFFSET = 0.000 DEG

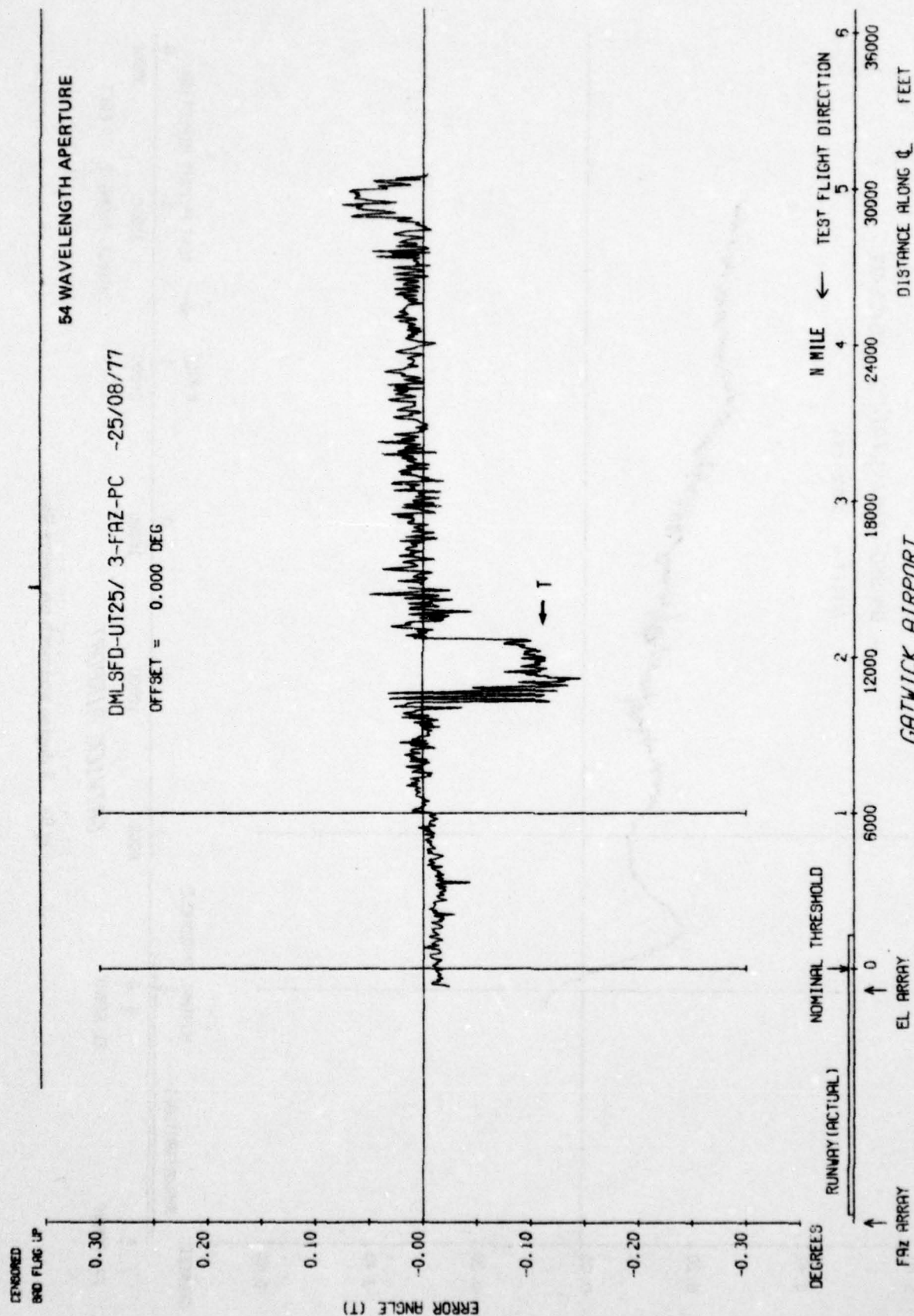


Fig 9b 3 degree approach on centre line

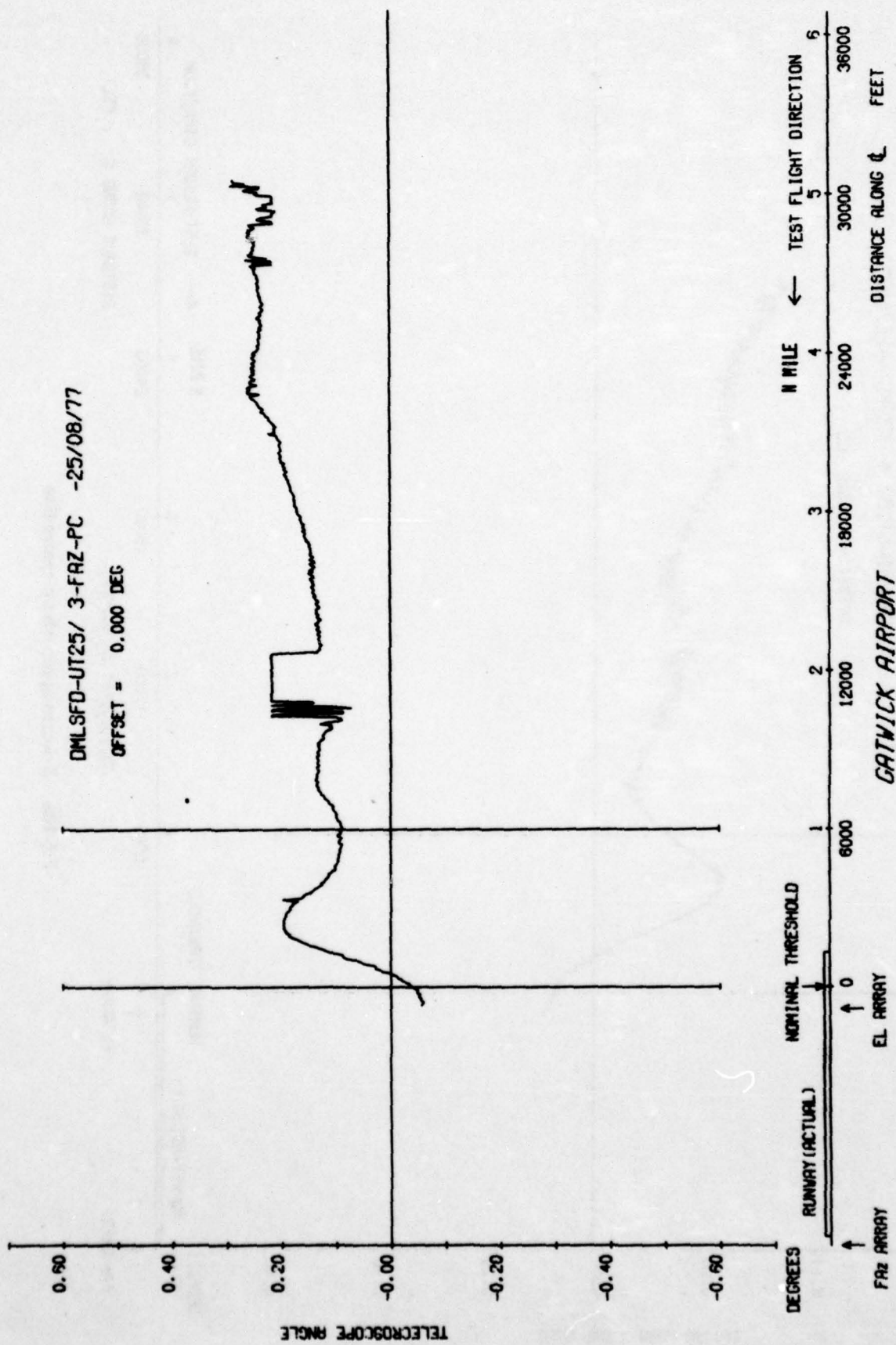


Fig 9c 3 degree approach on centre line

Fig 9c

Fig 10a

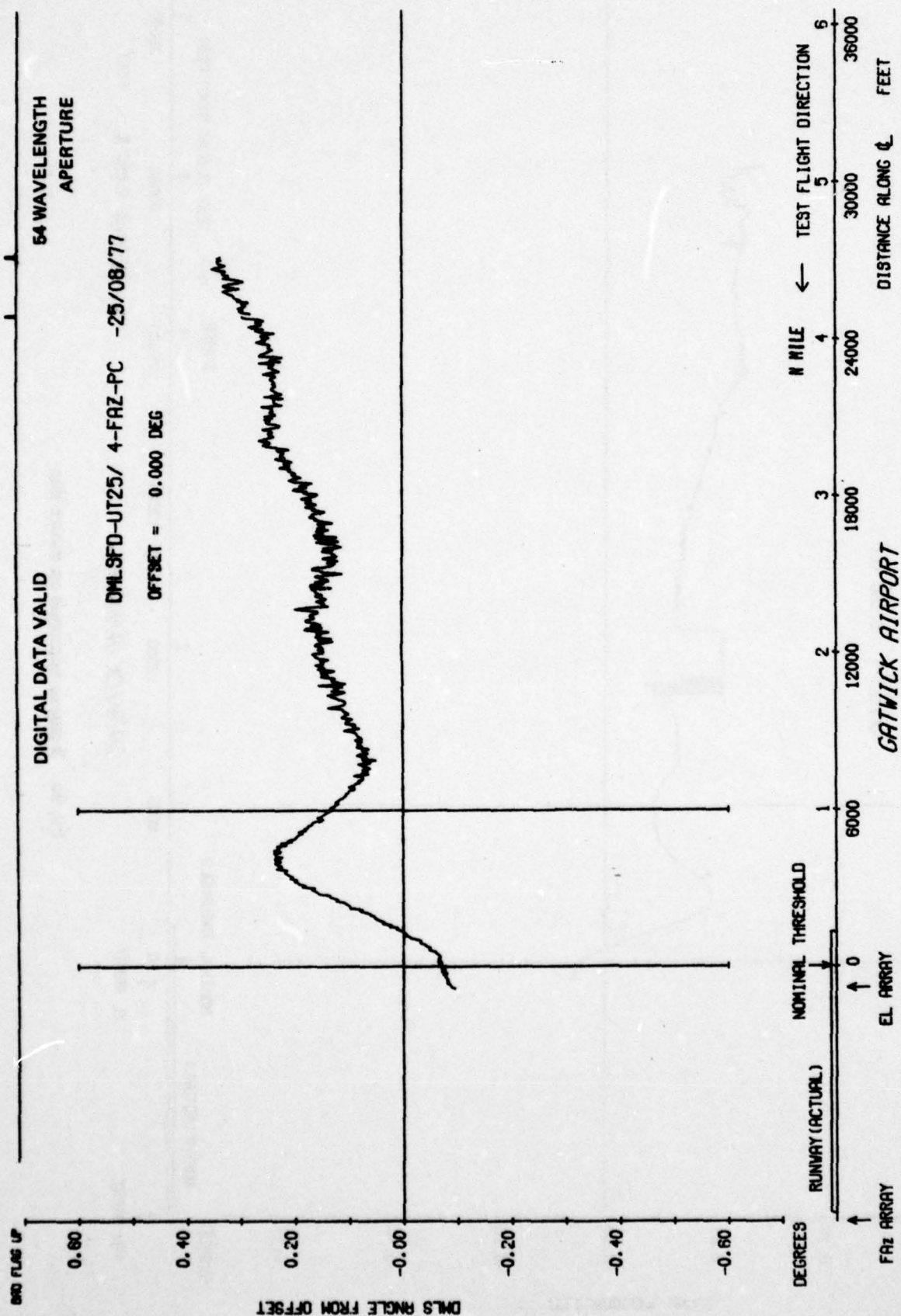


Fig 10a 3 degree approach on centre line

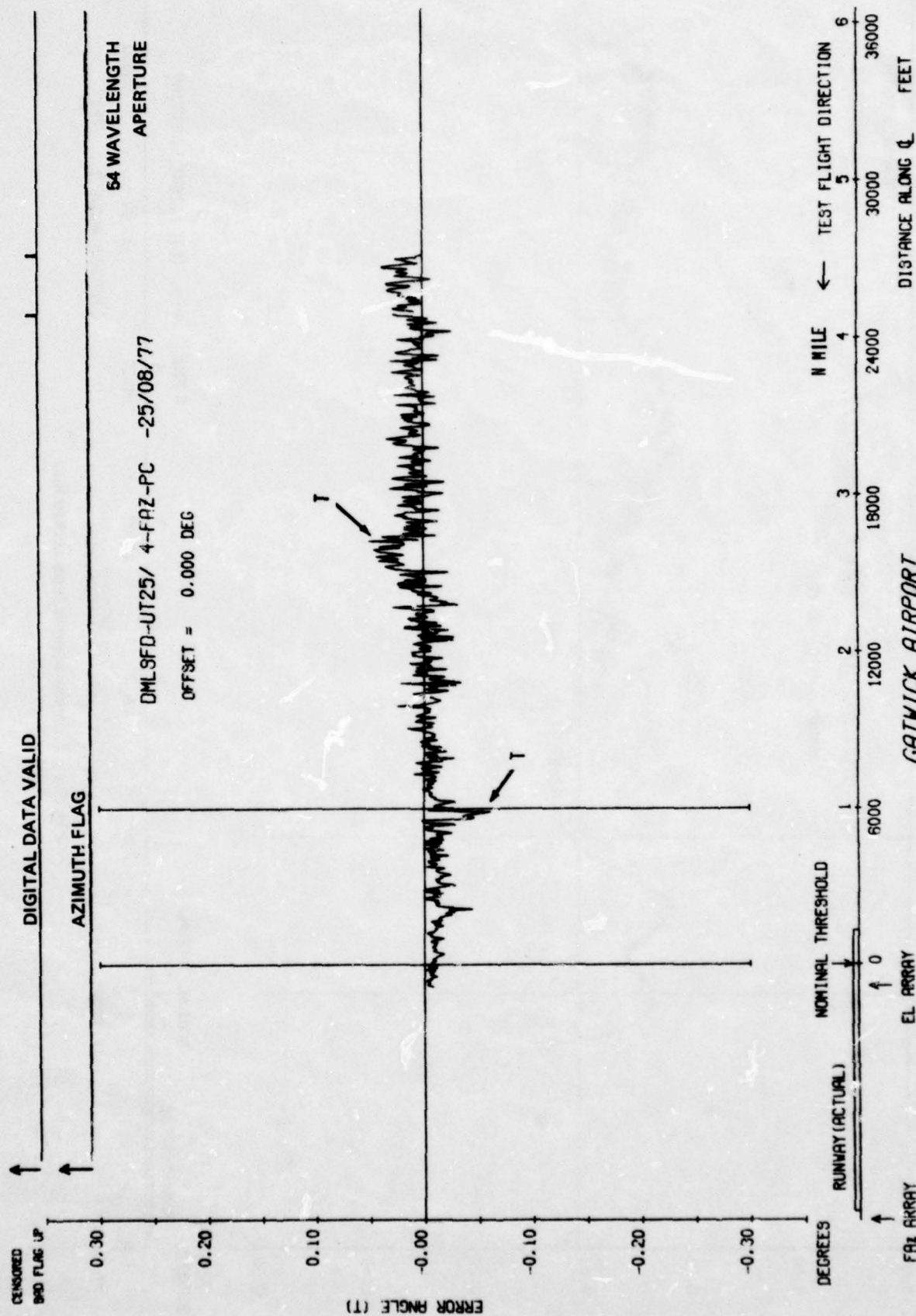


Fig 10b

Fig 11a

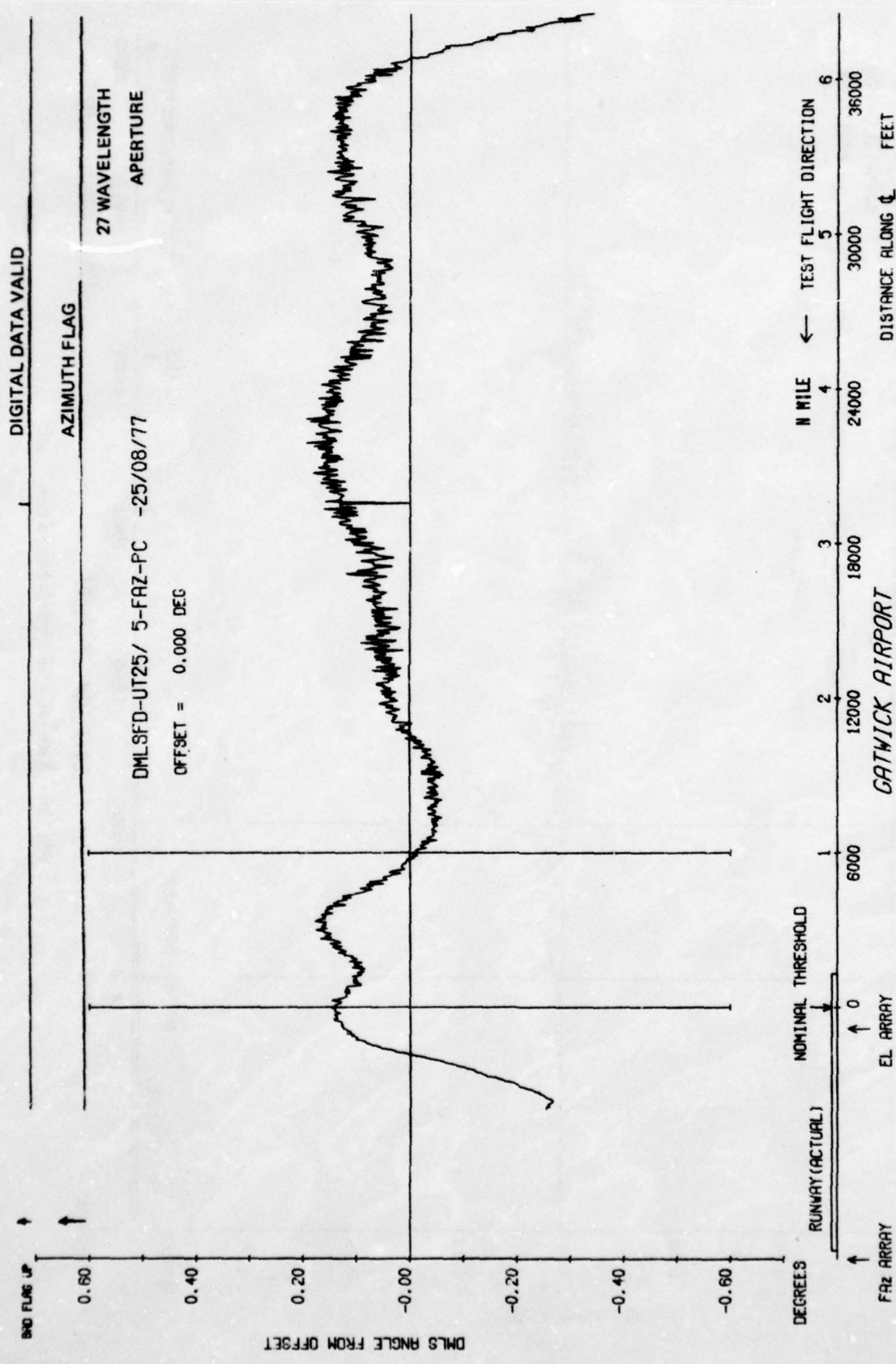


Fig 11a 3 degree approach on centre line

TR 78124

CENSORED
BAD FLAG UP

DIGITAL DATA VALID

AZIMUTH FLAG

27 WAVELENGTH
APERTURE

DMLSFD-UT25/ 5-FRZ-PC -25/08/77

OFFSET = 0.000 DEG

ERROR ANGLE (T)

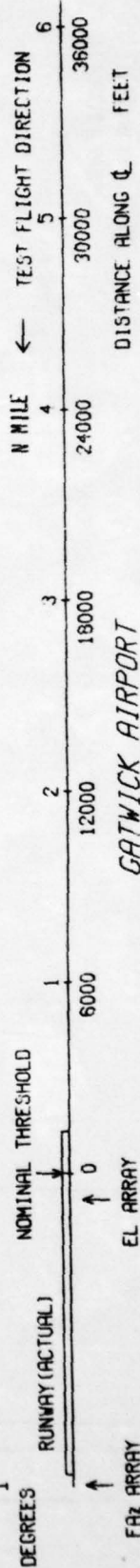
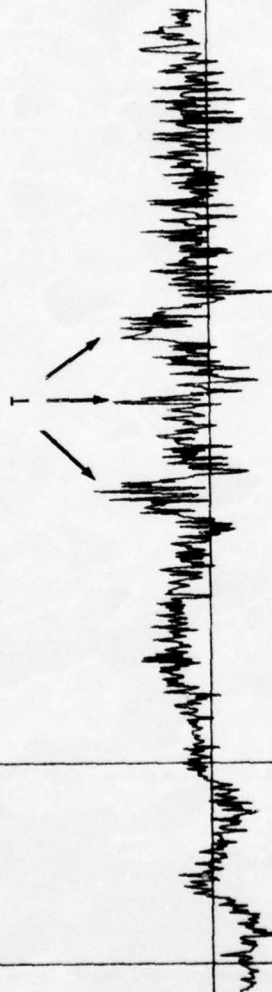


Fig 11b 3 degree approach on centre line

Fig 12a

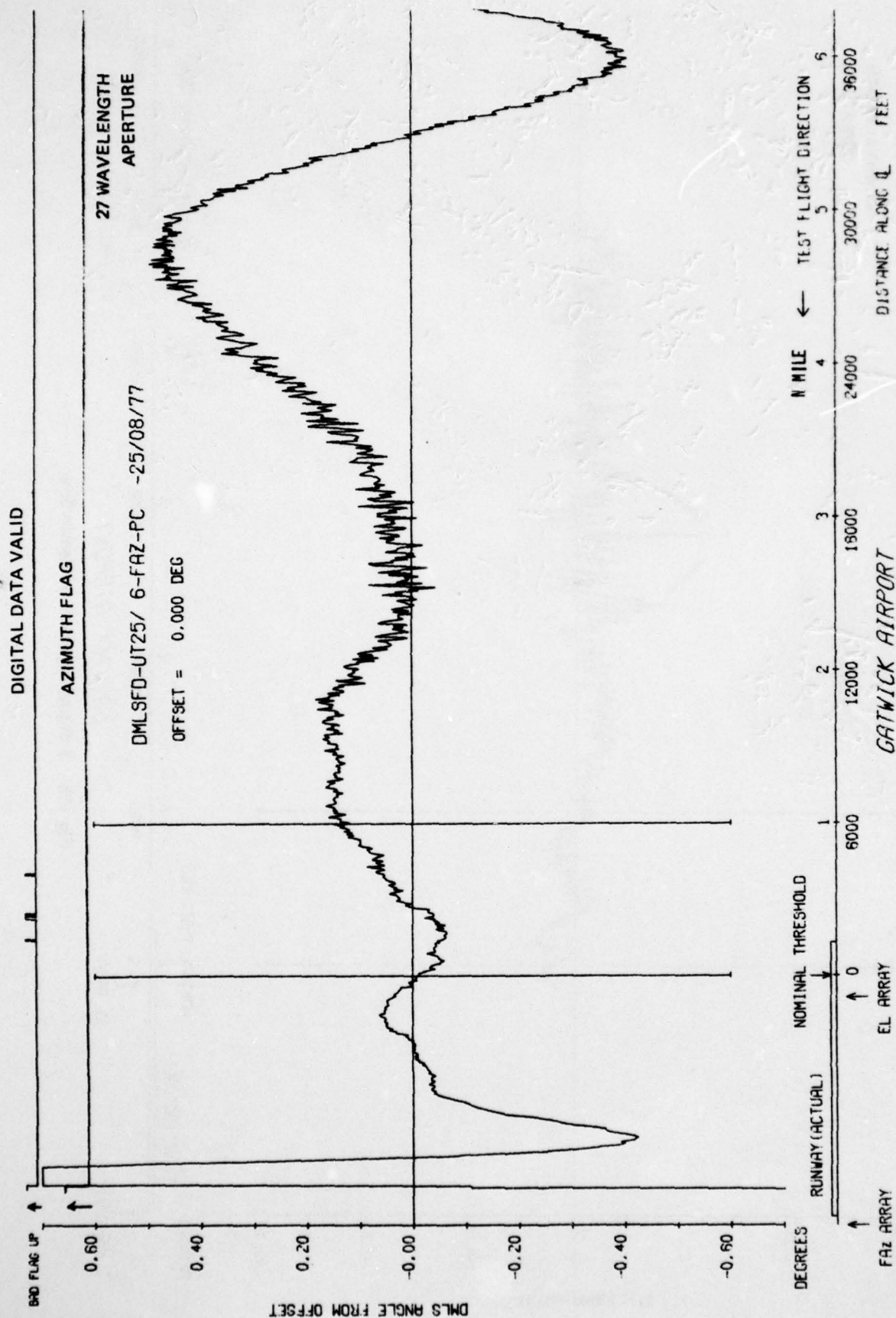


Fig 12a 3 degree approach on centre line

TR 78124

CENSORED

500 FLAG UP

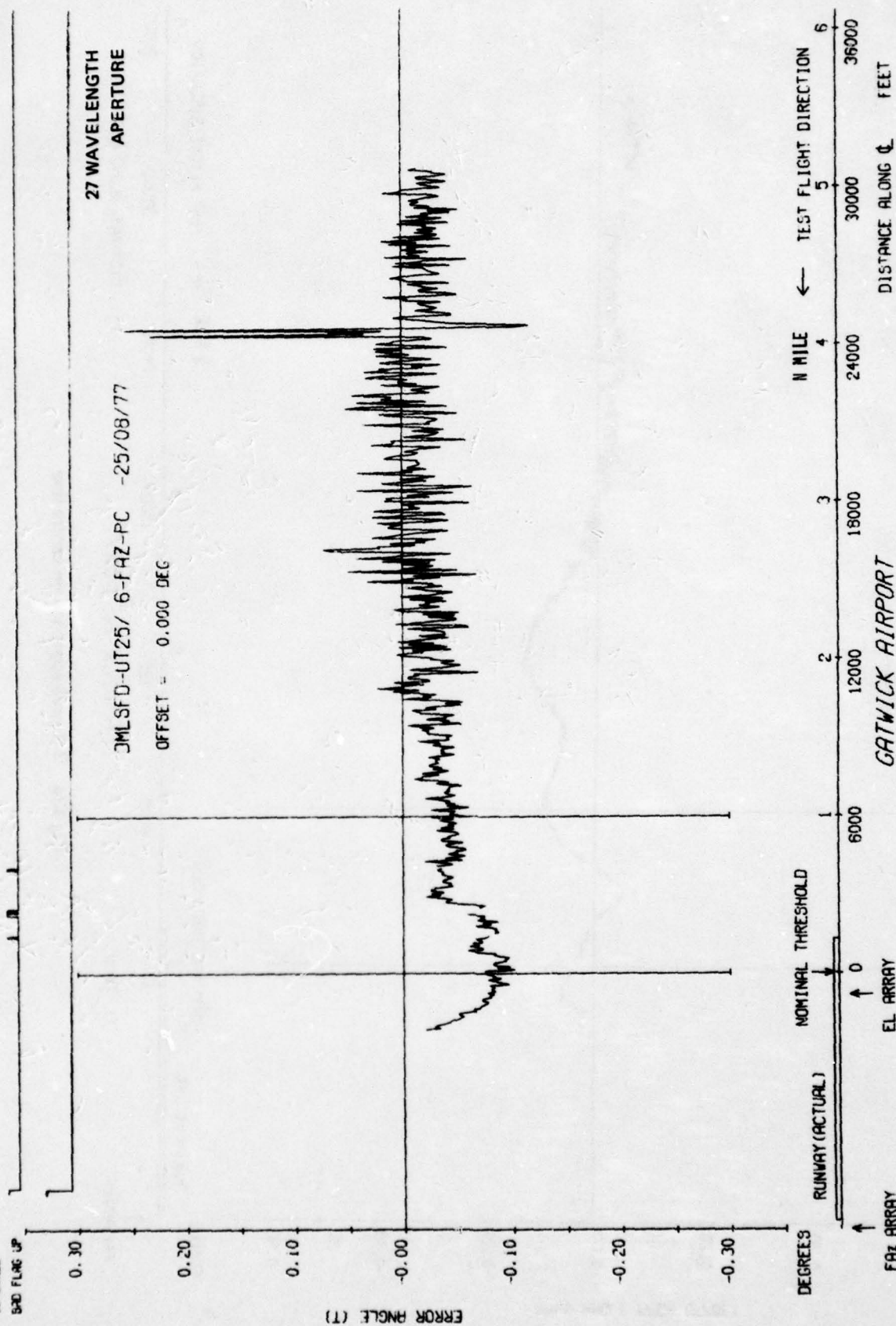
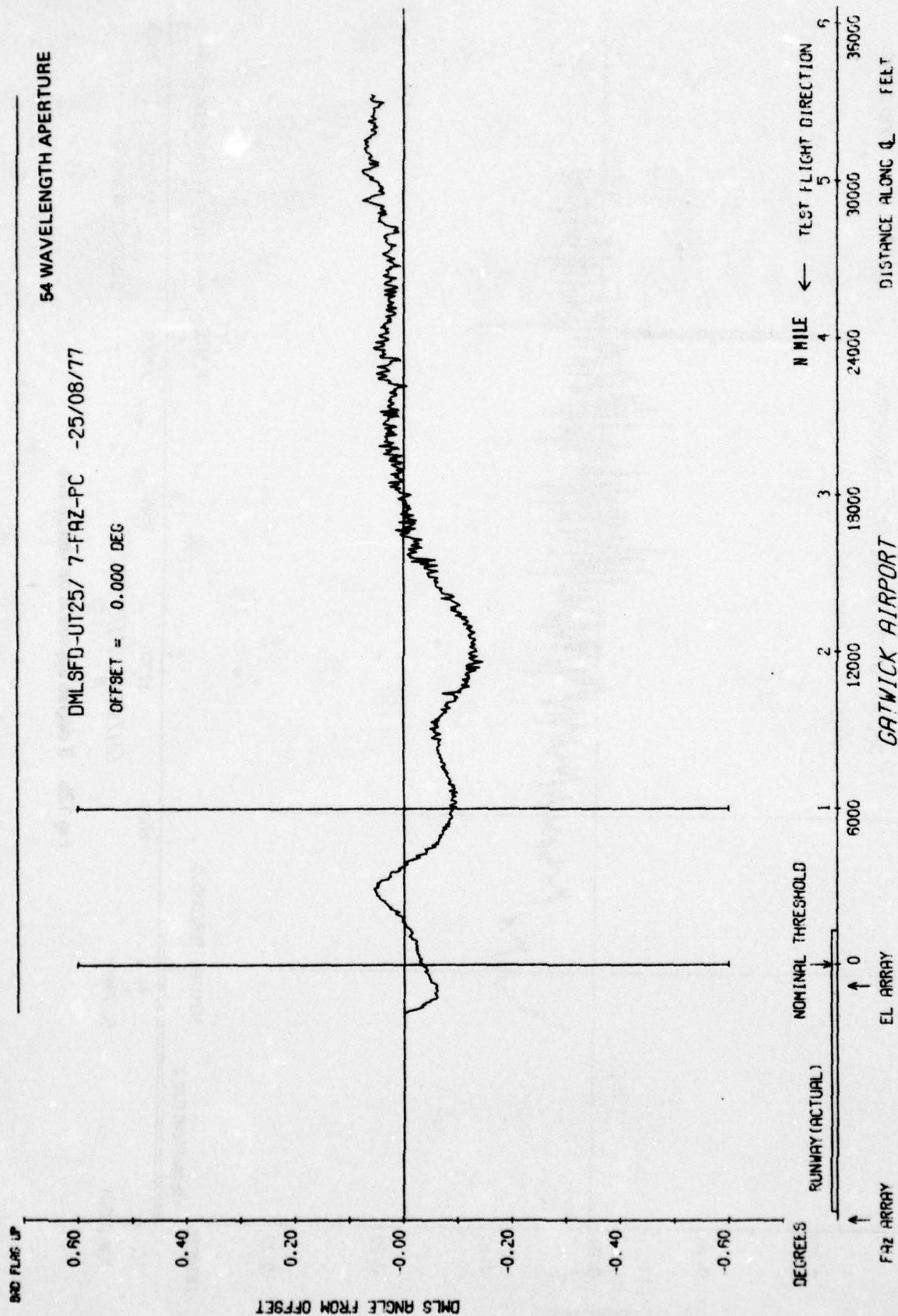


Fig 12b

Fig 12b 3 degree approach on centre line

Fig 13a



CENSORED
SPC FLAG UP

54 WAVELENGTH APERTURE

DMLSFD-UT25/ 7-44Z-PC -25/08/77

OFFSET = 0.000 DEG

ERROR ANGLE (T)

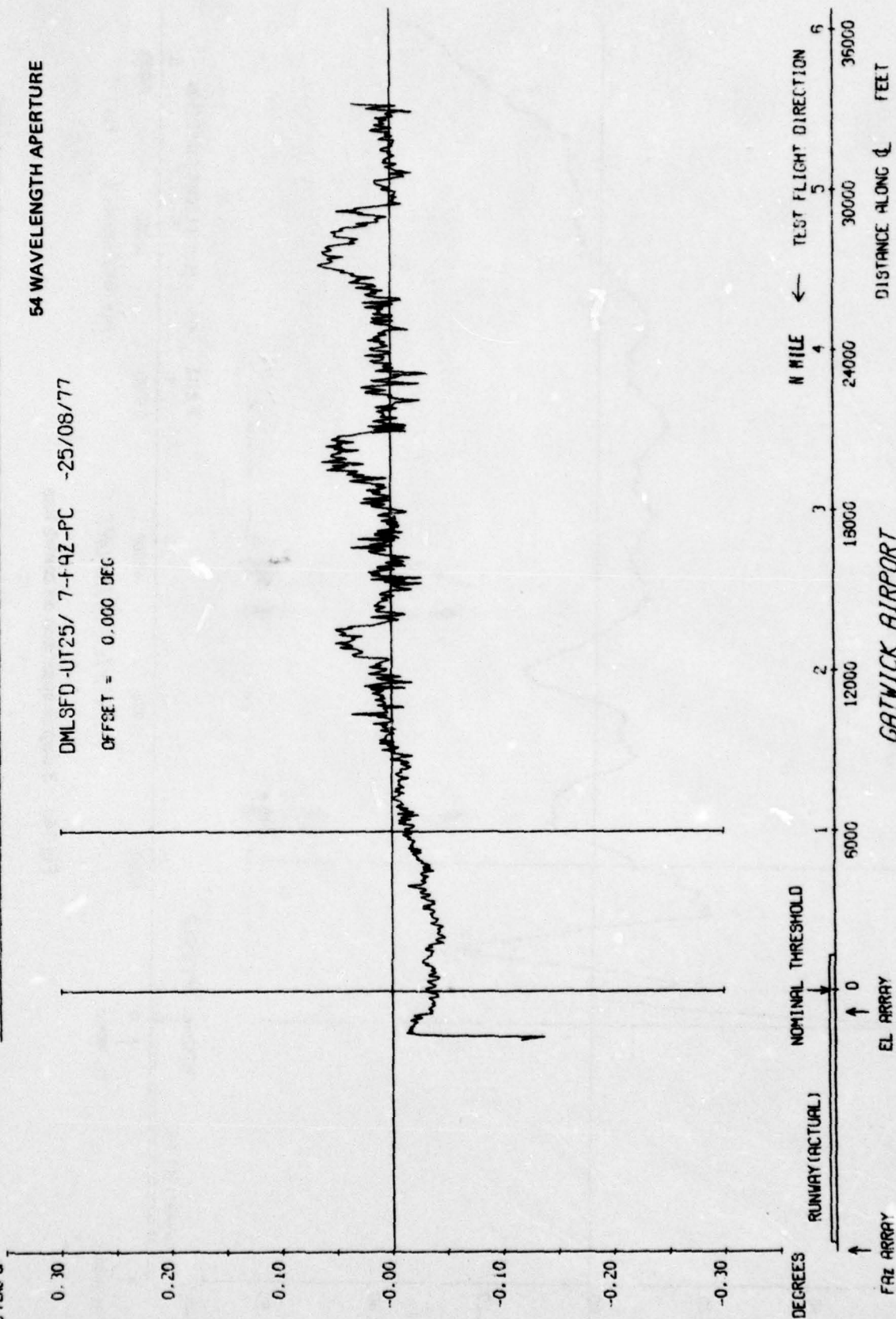


Fig 13b 3 degree approach on centre line

Fig 14a

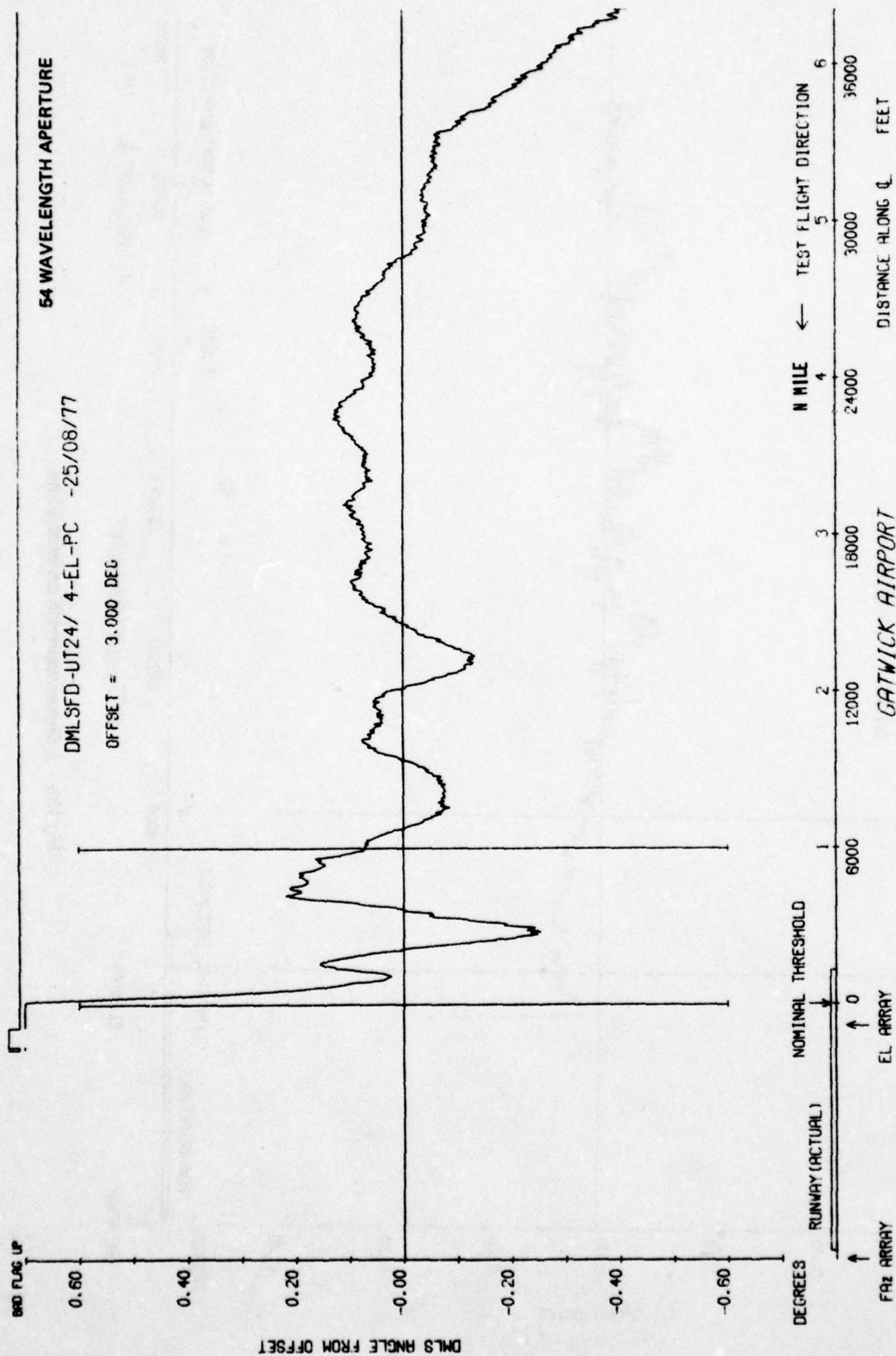


Fig 14a 3 degree approach on centre line

CENSORED
BND FLAG UP

54 WAVELENGTH APERTURE

DMLSFD-UT24/ 4-EL-PC -25/08/77

OFFSET = 3.000 DEG

ERROR ANGLE (T)

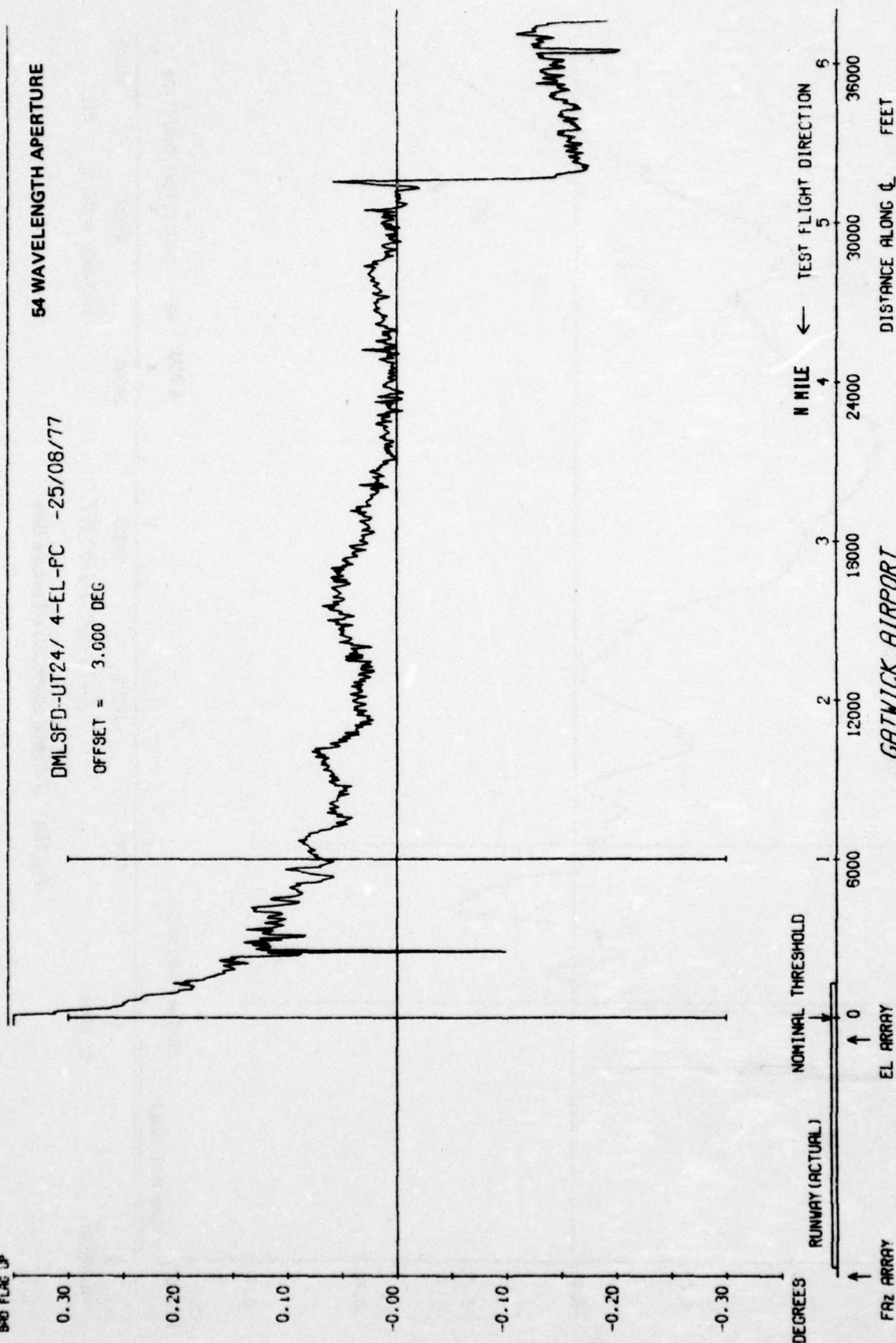


Fig 14b

Fig 14b 3 degree approach on centre line

Fig 15a

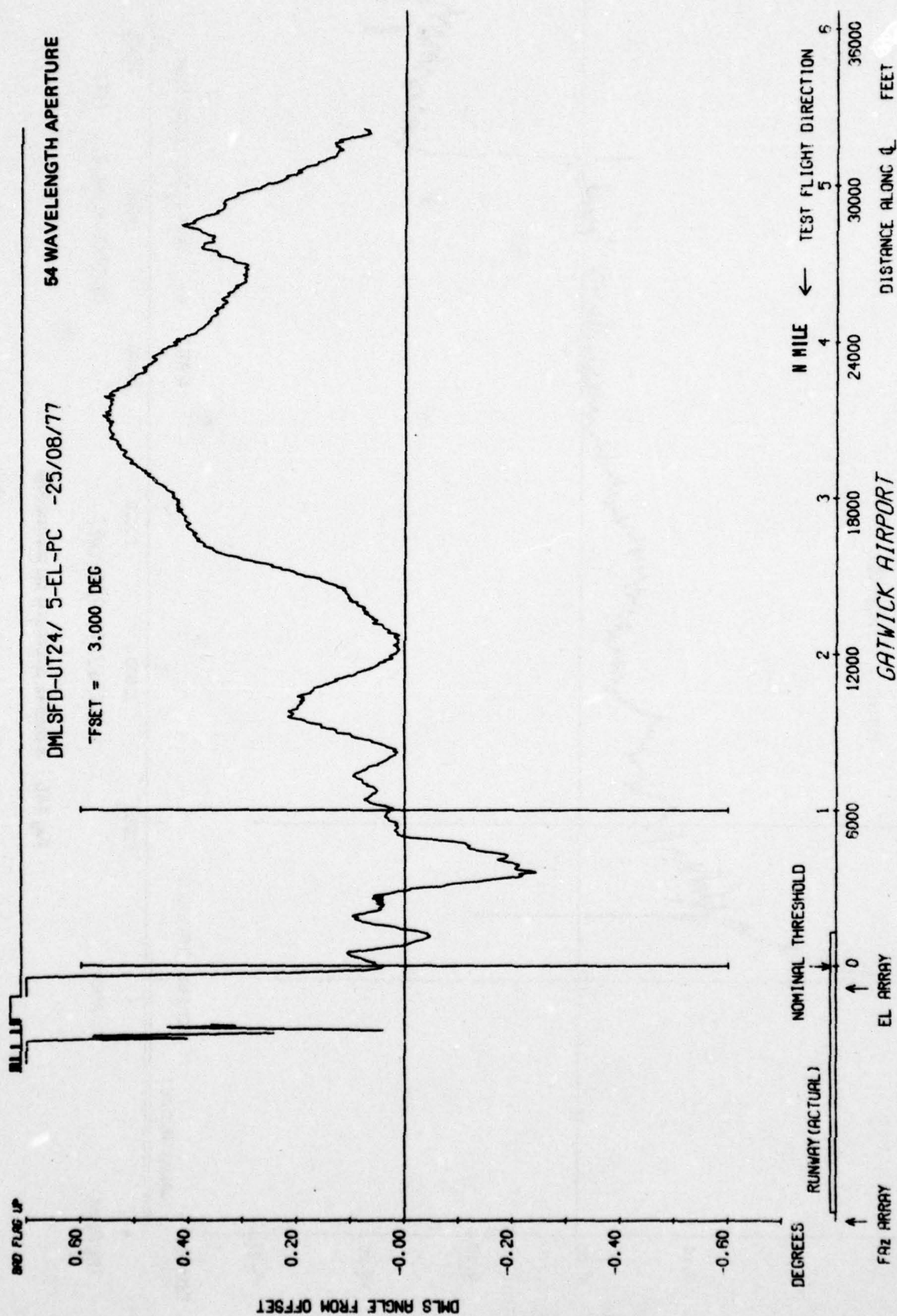


Fig 15a 3 degree approach on centre line

CENSORED
BND FLAG UP

54 WAVELENGTH APERTURE

DMLSFD-UT24/ 5-EL-PC -25/08/77

OFFSET = 3.000 DEG

ERROR ANGLE (1)

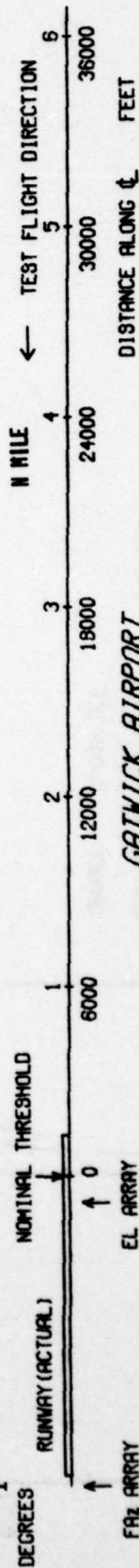


Fig 16a

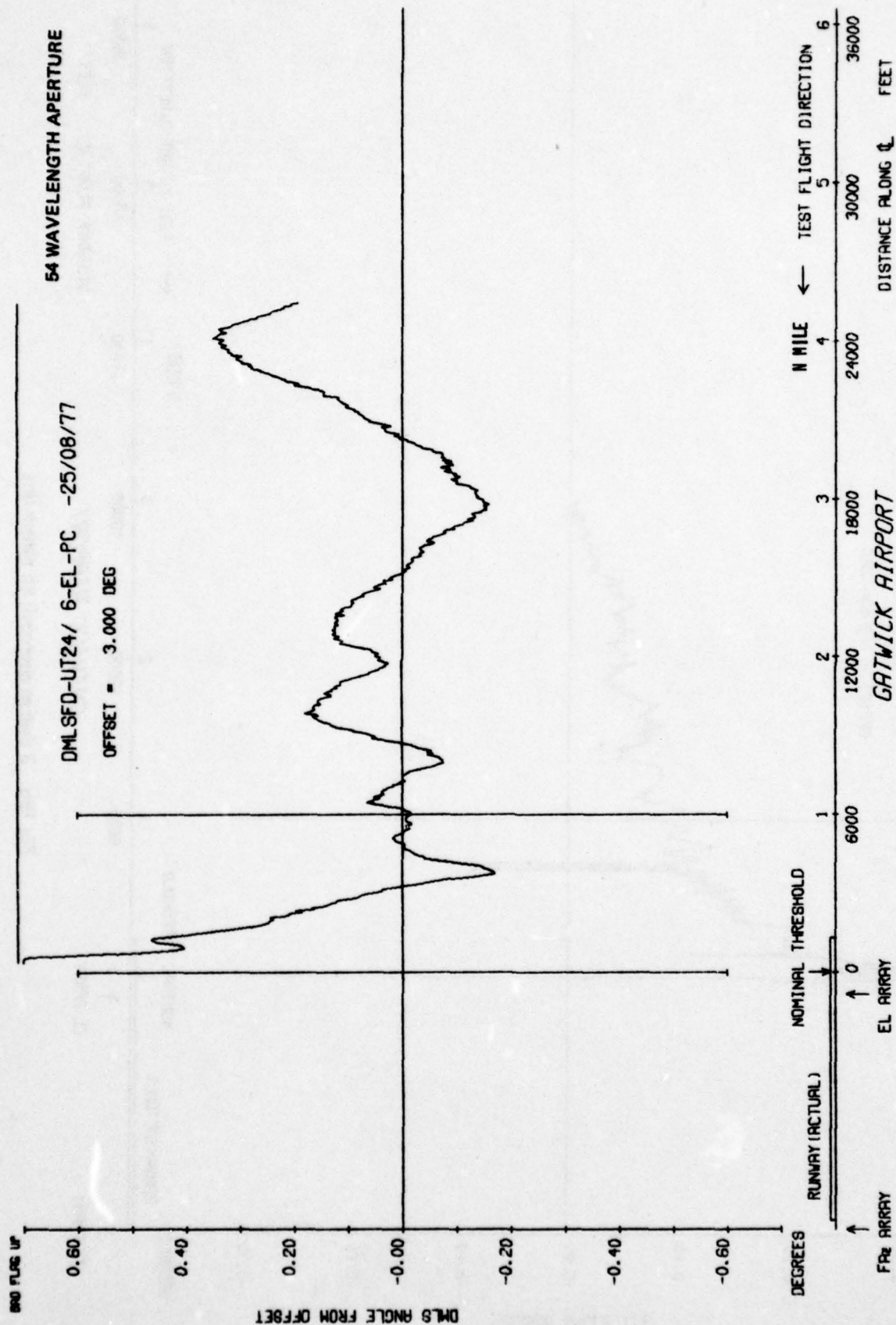


Fig 16a 3 degree approach on centre line

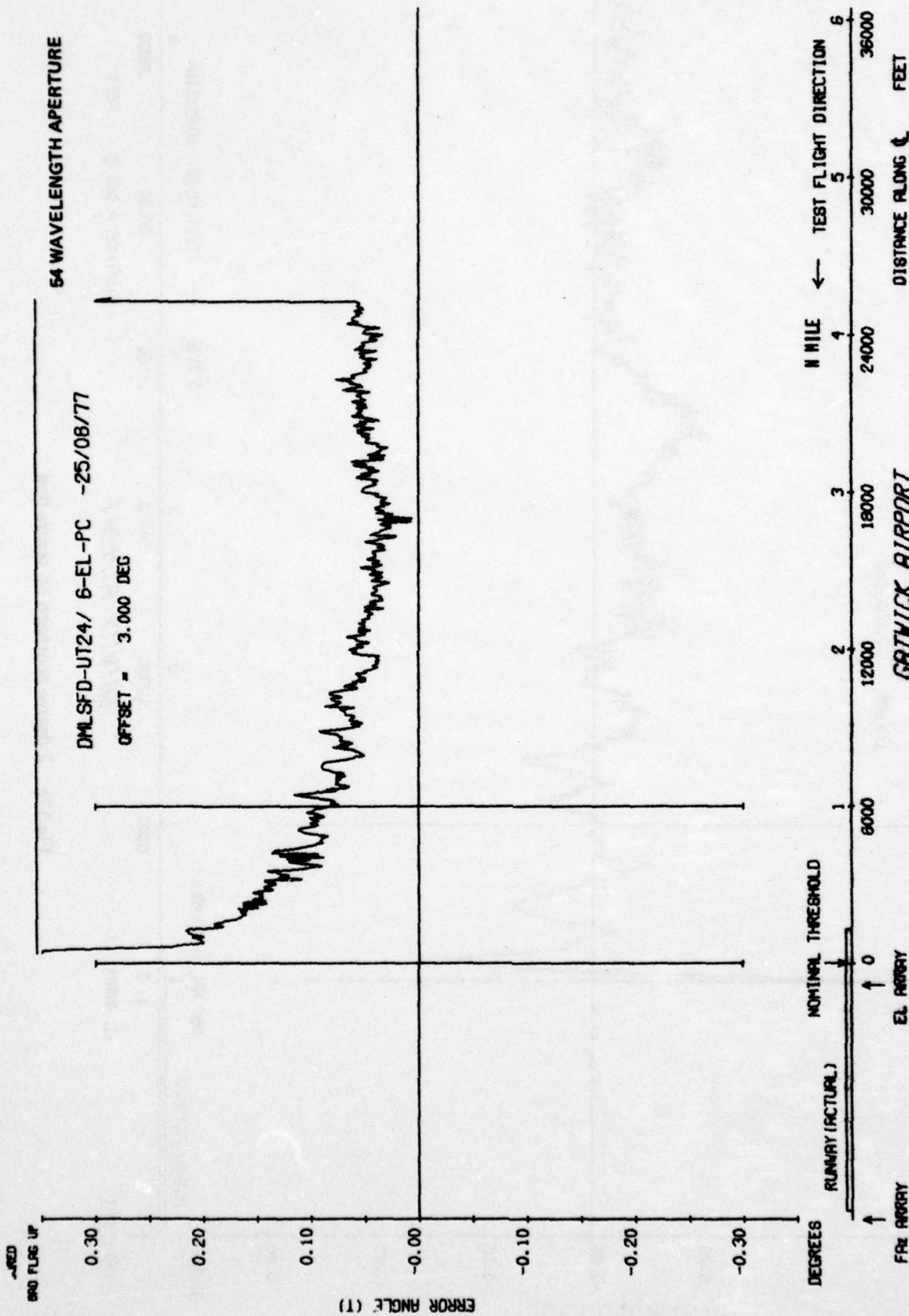


Fig 16b

Fig 16b 3 degrees approach on centre line

Fig 17a

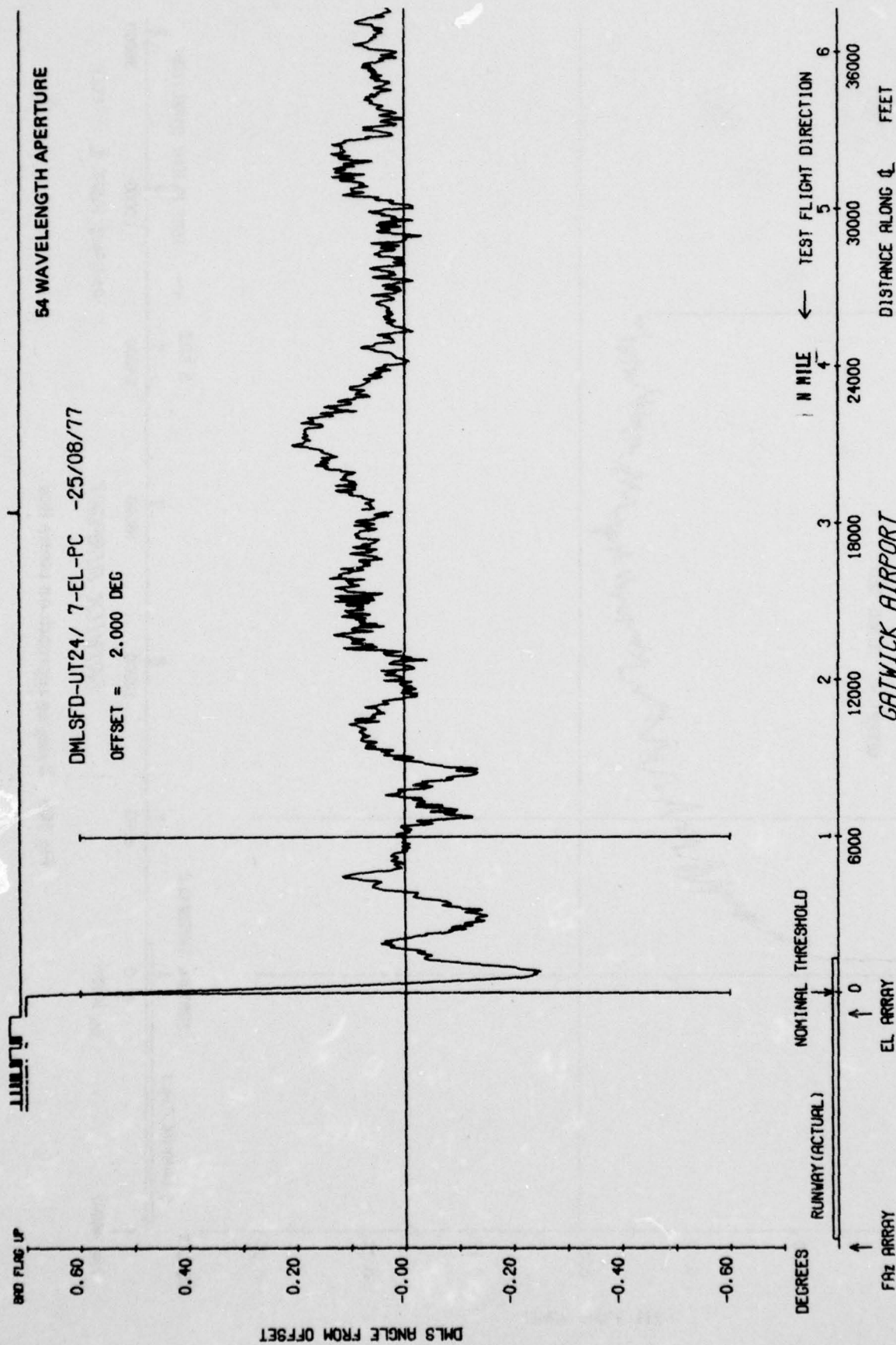


Fig 17a 2 degree approach on centre line

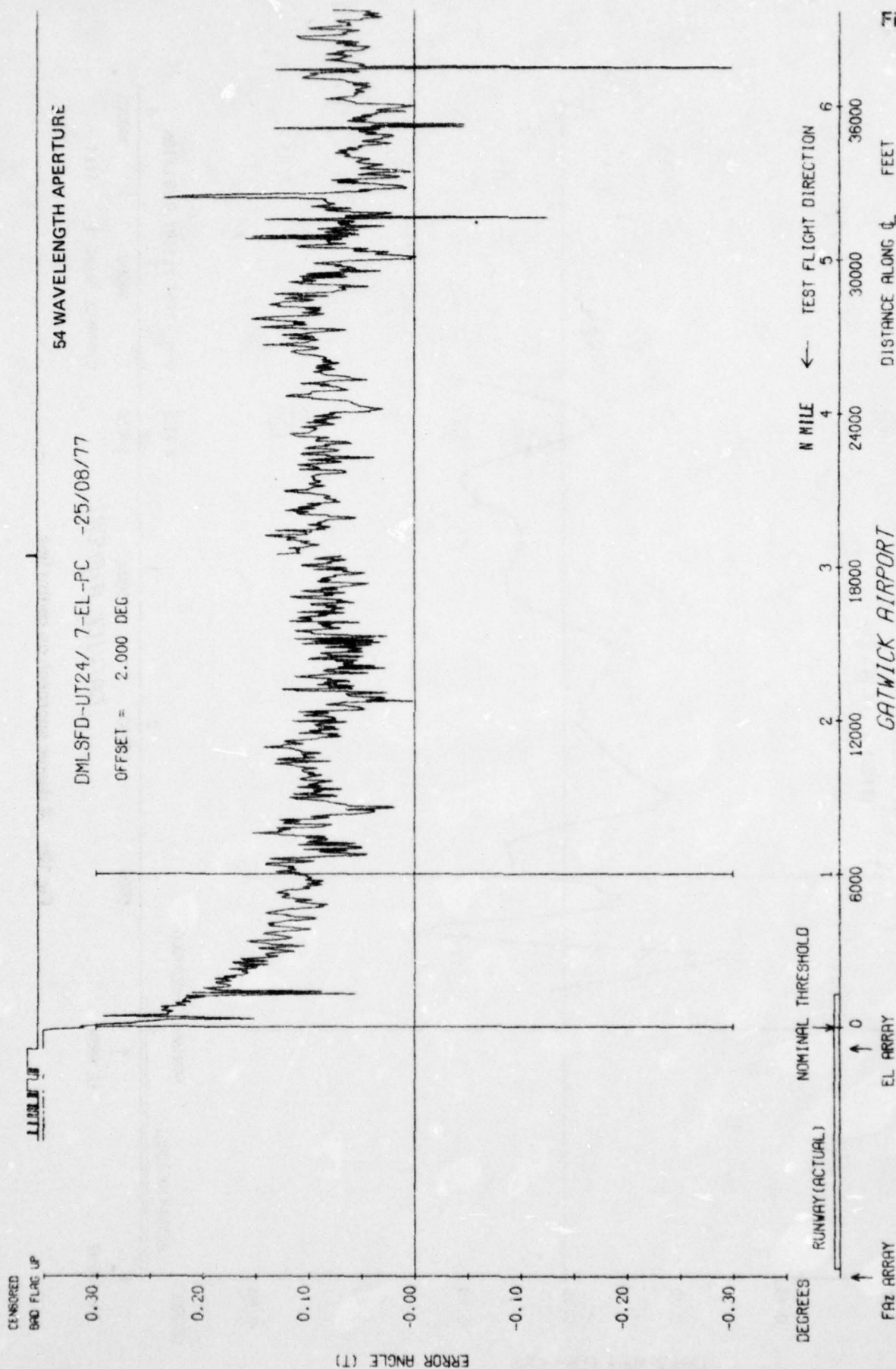


Fig 17b 2 degree approach on centre line

Fig 18a

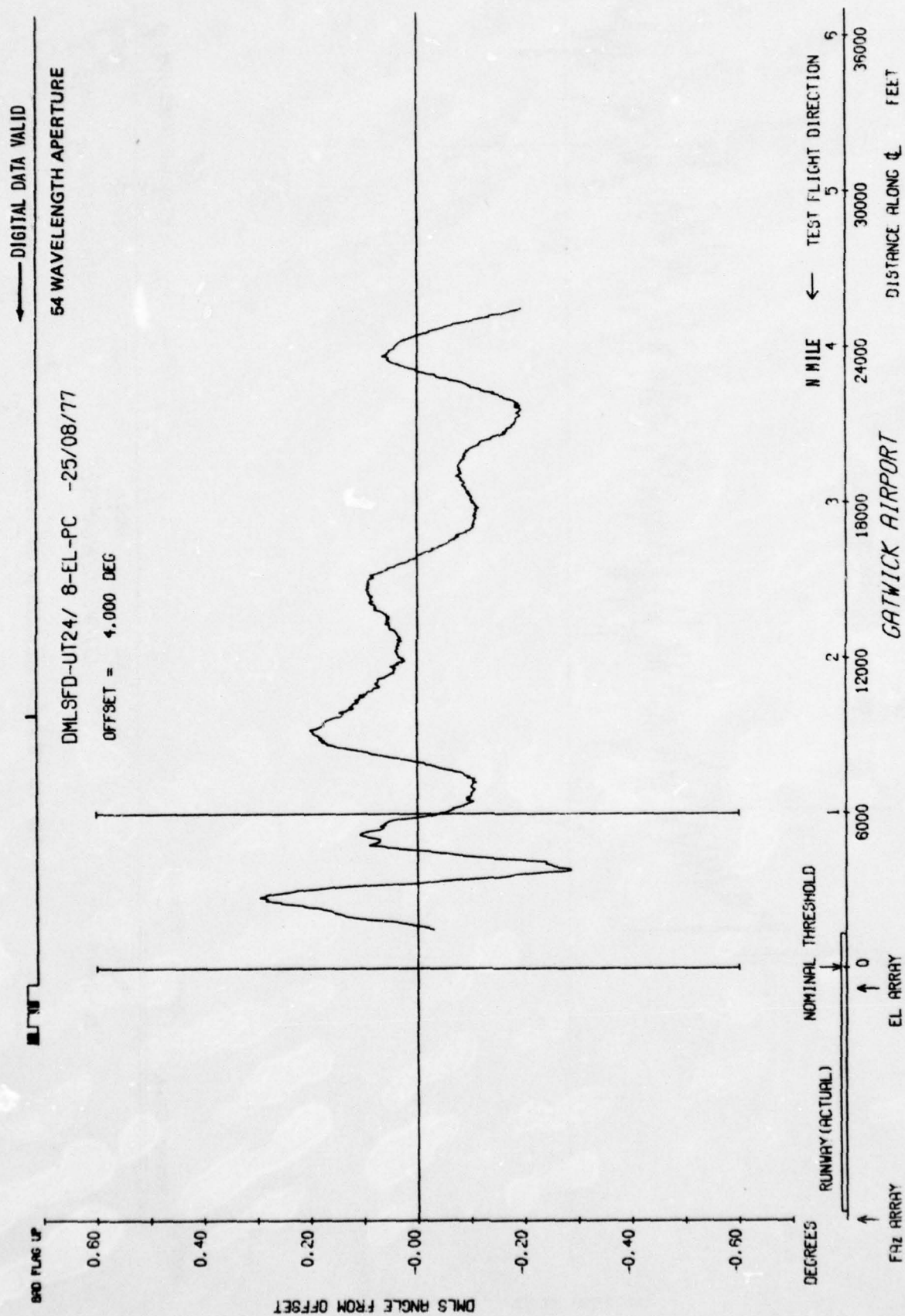


Fig 18a 4 degree approach on centre line

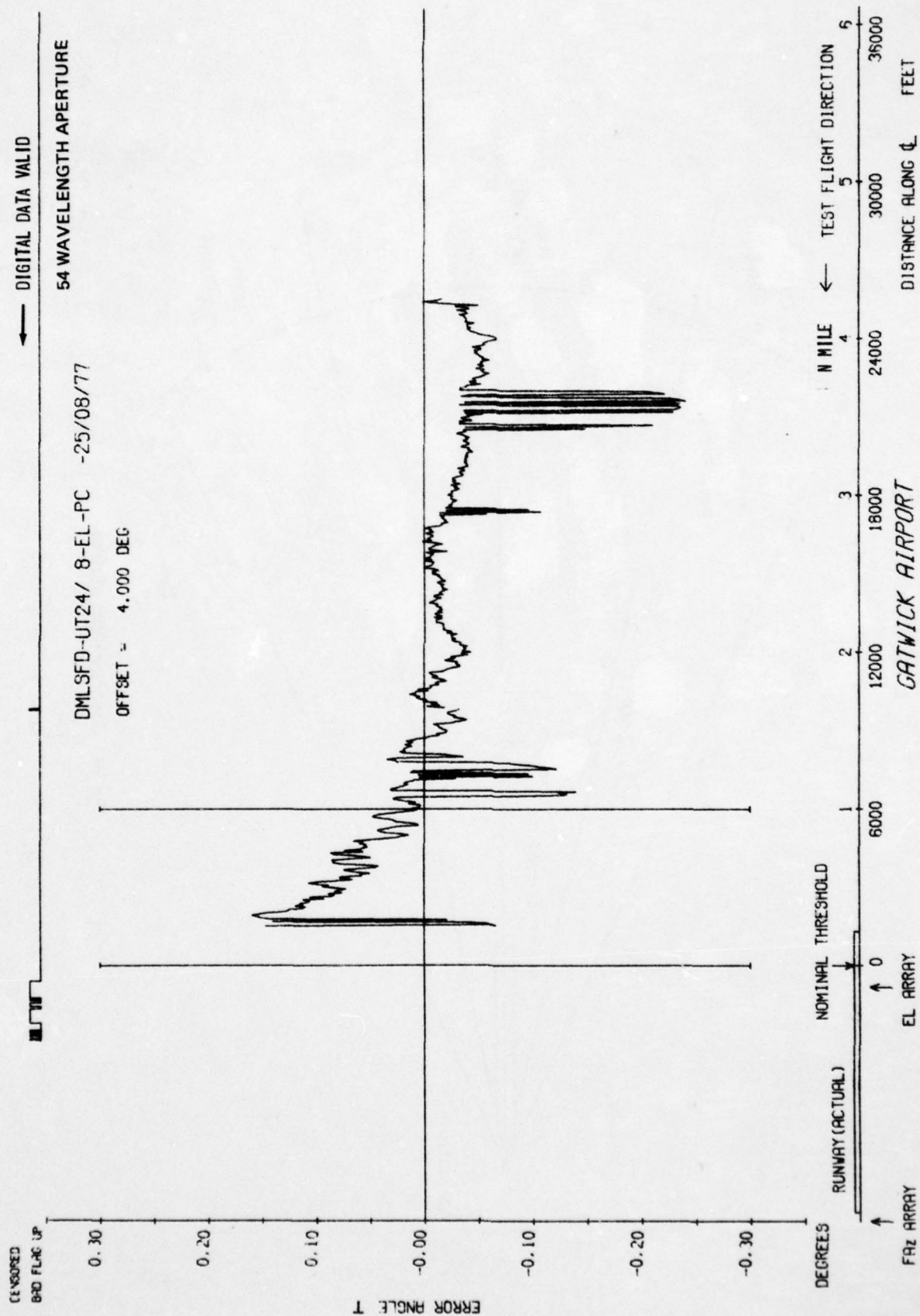


Fig 18b 4 degree approach on centre line

Fig 19

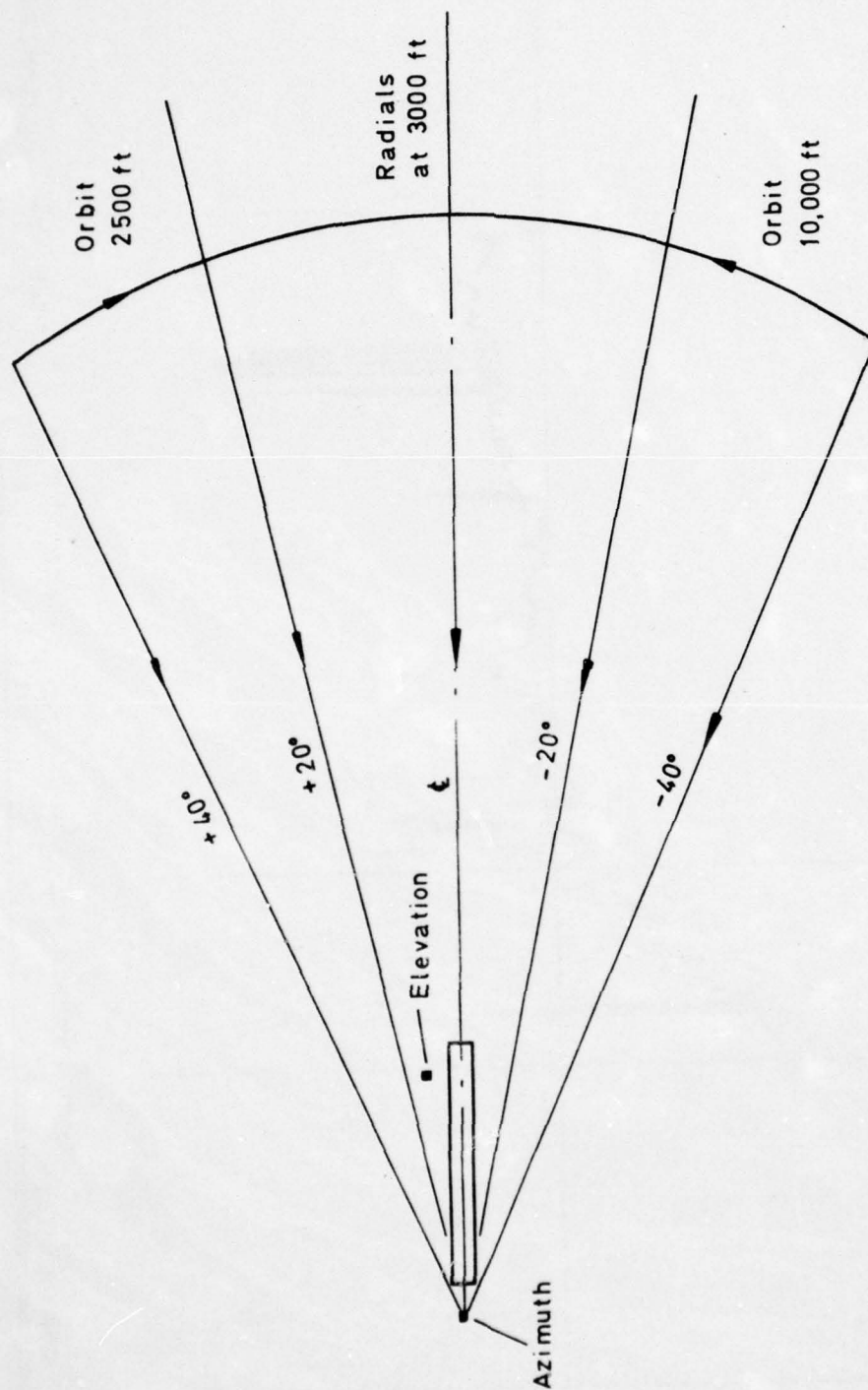


Fig 19 Coverage flight profiles

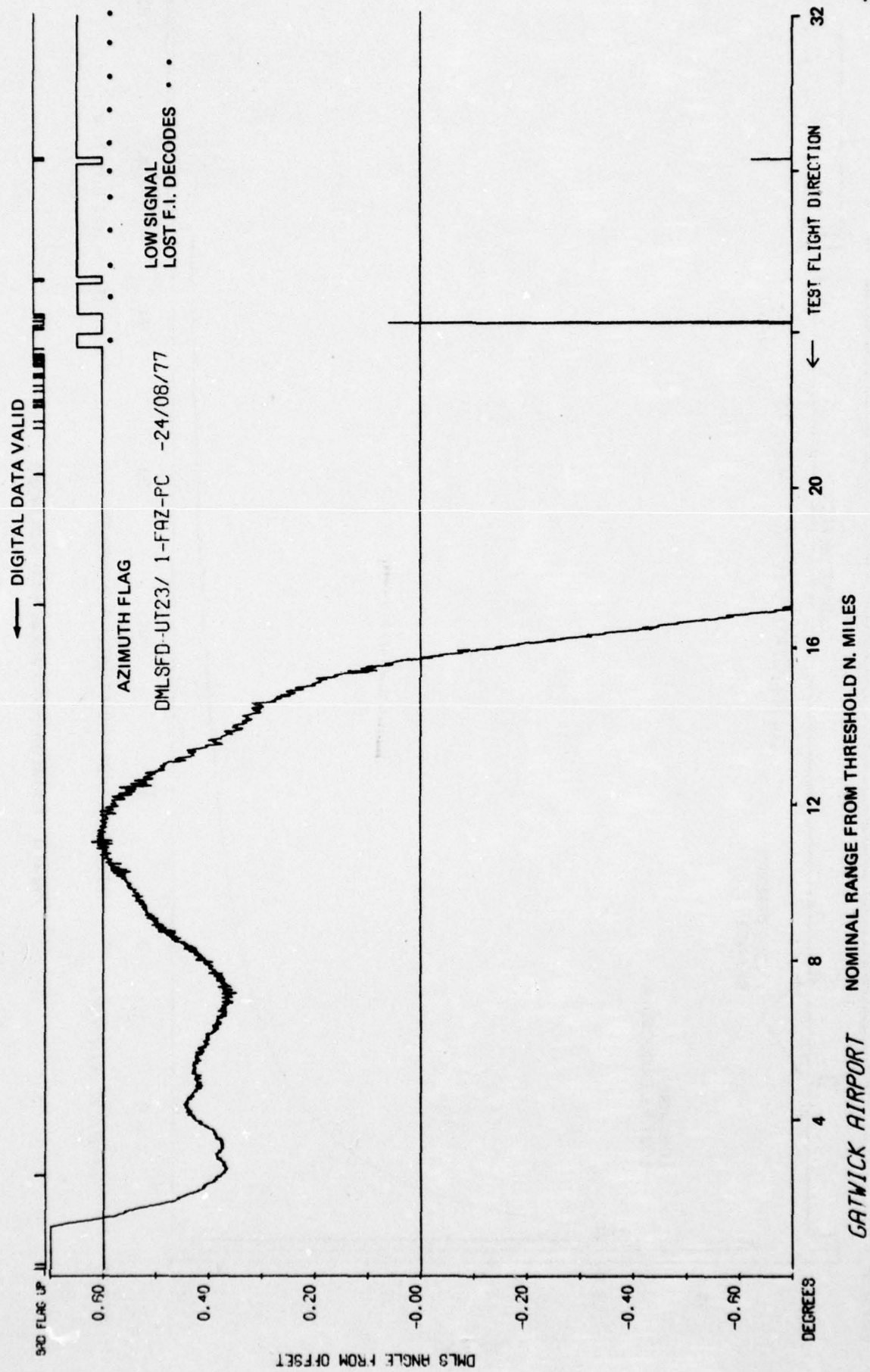


Fig 20a

Fig 20a Radial on centre line at 3000 foot height

Fig 20b

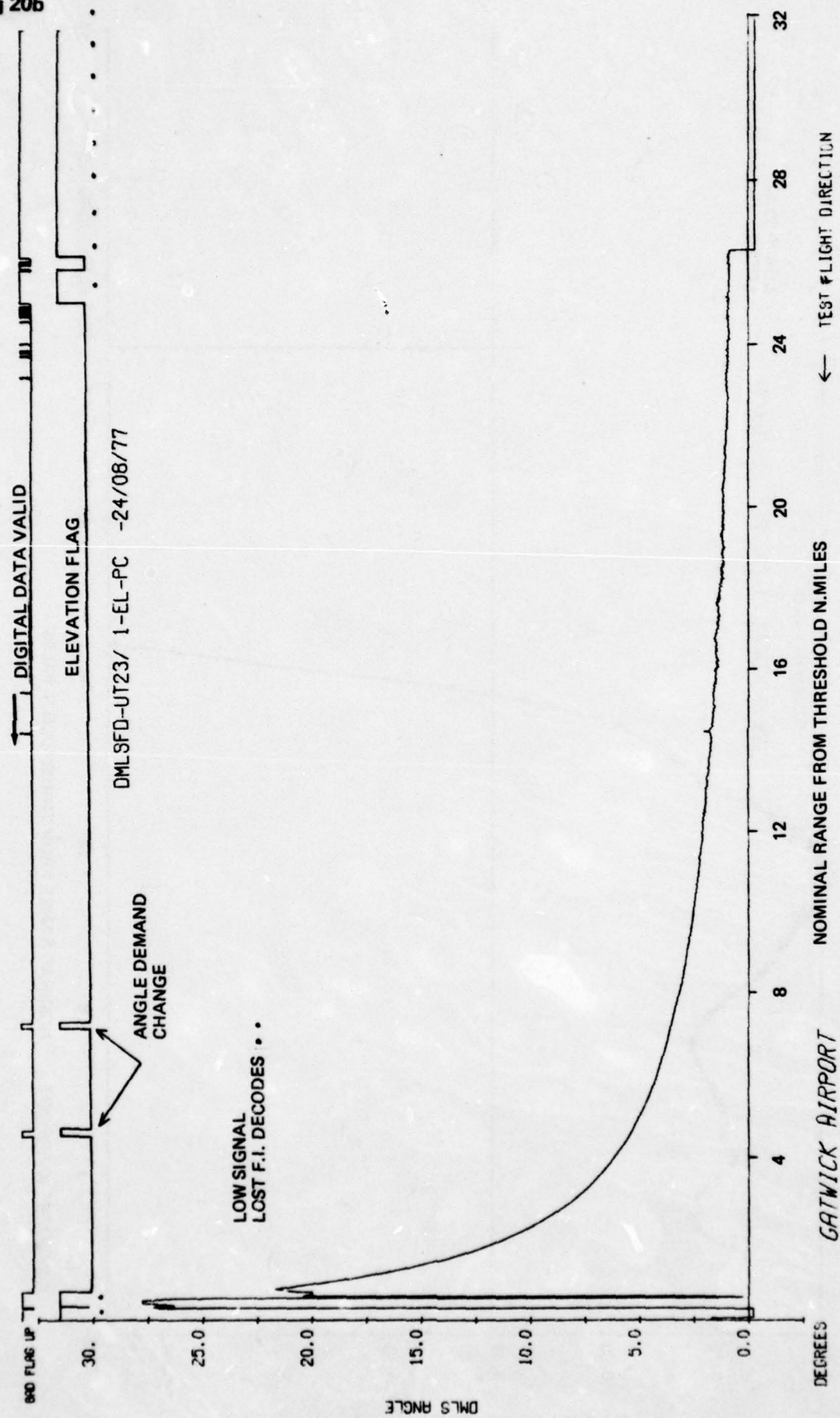


Fig 20b Radial on centre line at 3000 foot height

Fig 21a

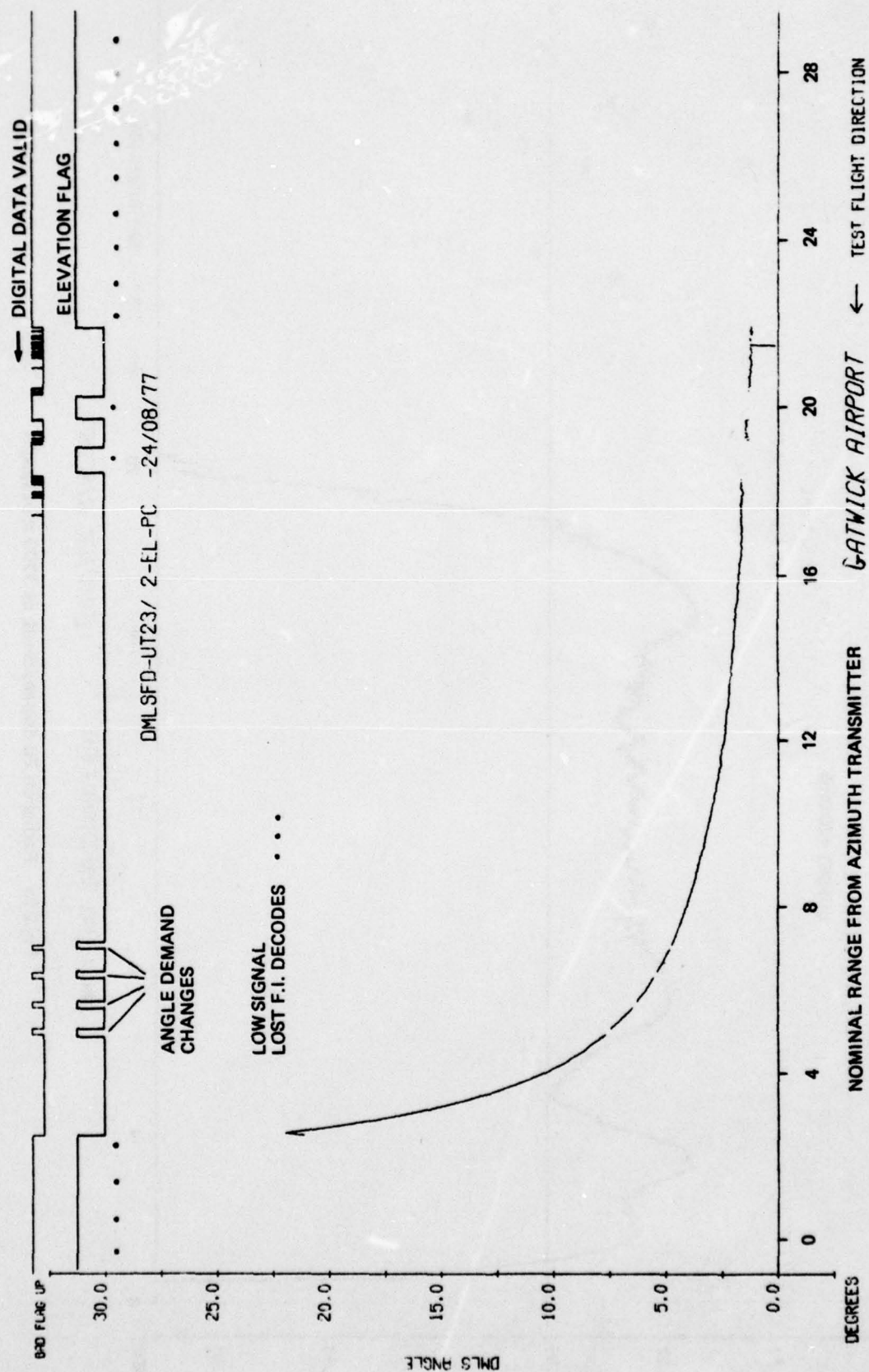


Fig 21a Radial on 20 degrees south at 3000 foot height

Fig 21b

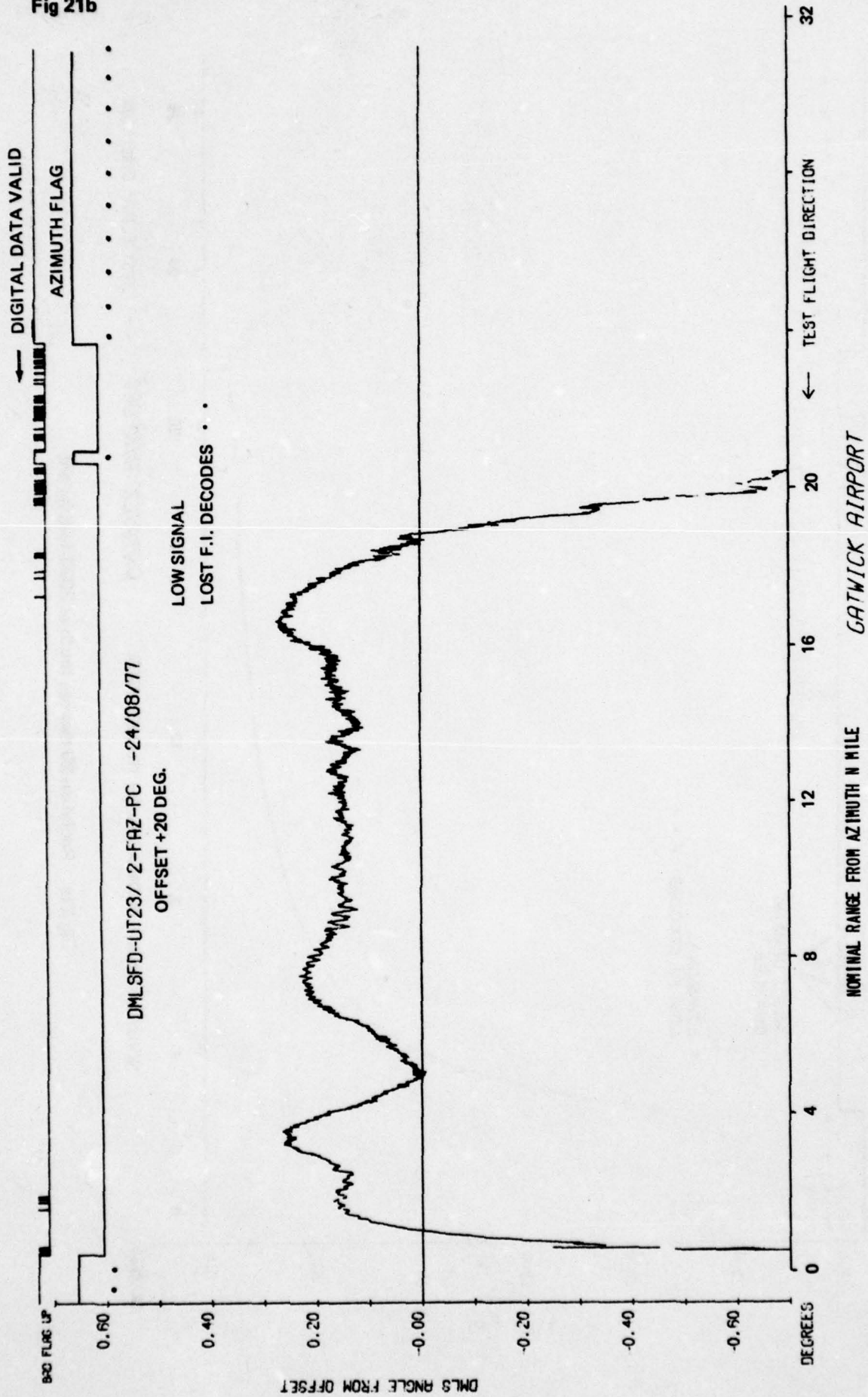


Fig 21b Radial on 20 degrees south at 3000 foot height

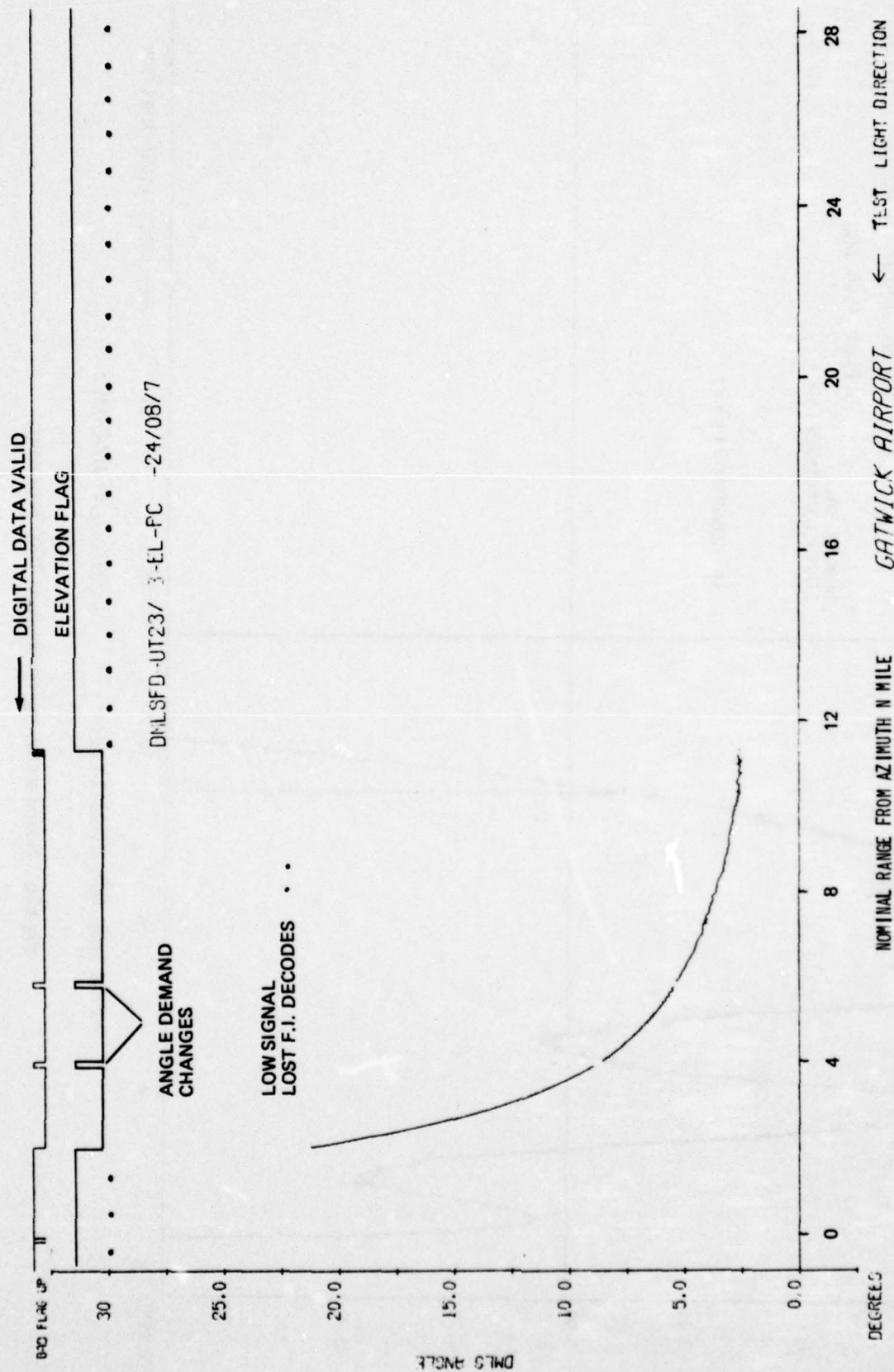


Fig 22a Radial on 40 degrees south at 3000 foot height

Fig 22b

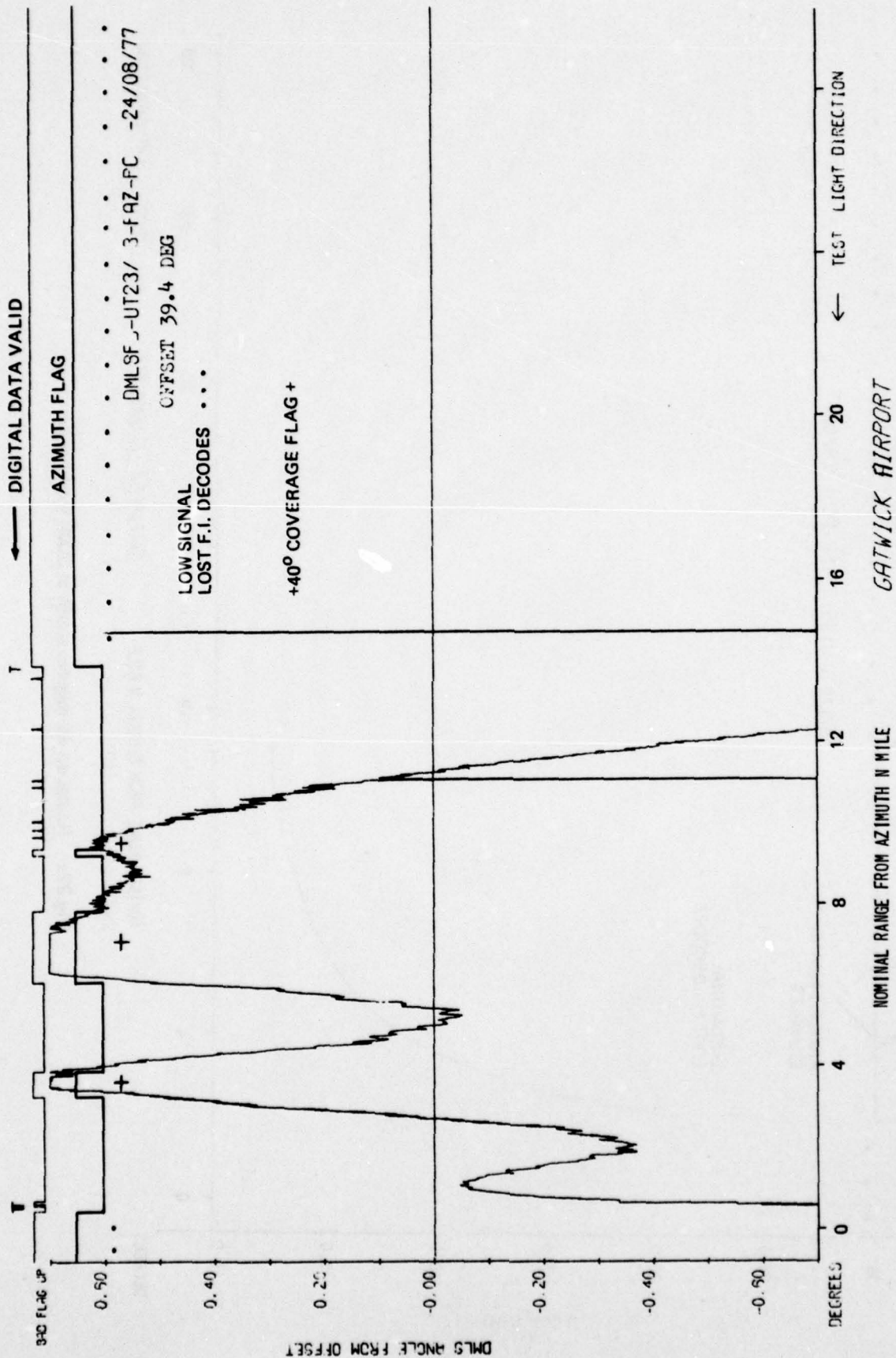


Fig 22b Radial on 40 degrees south at 3000 foot height

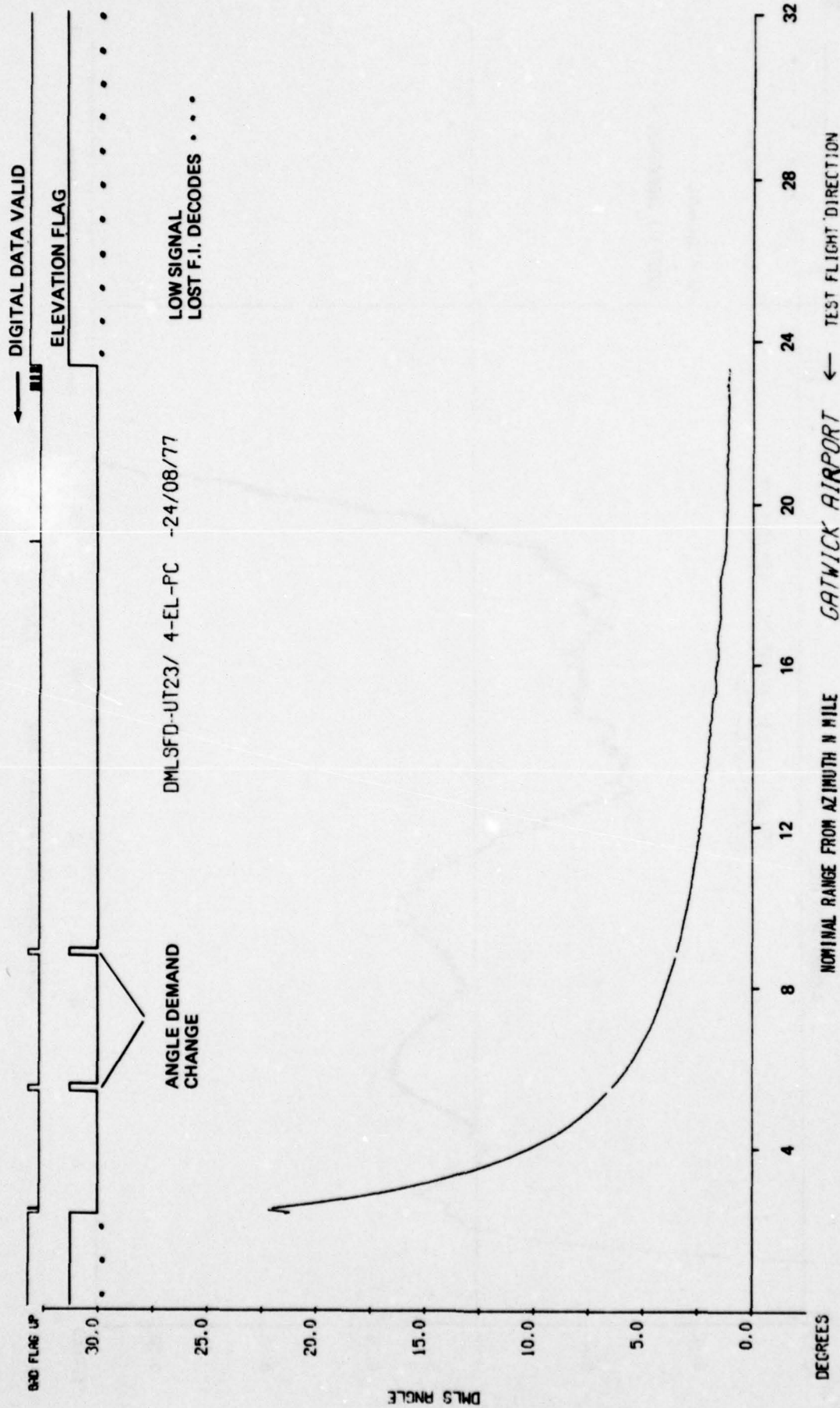


Fig 23a

Fig 23a Radial on 20 degrees north at 3000 foot height

Fig 23b

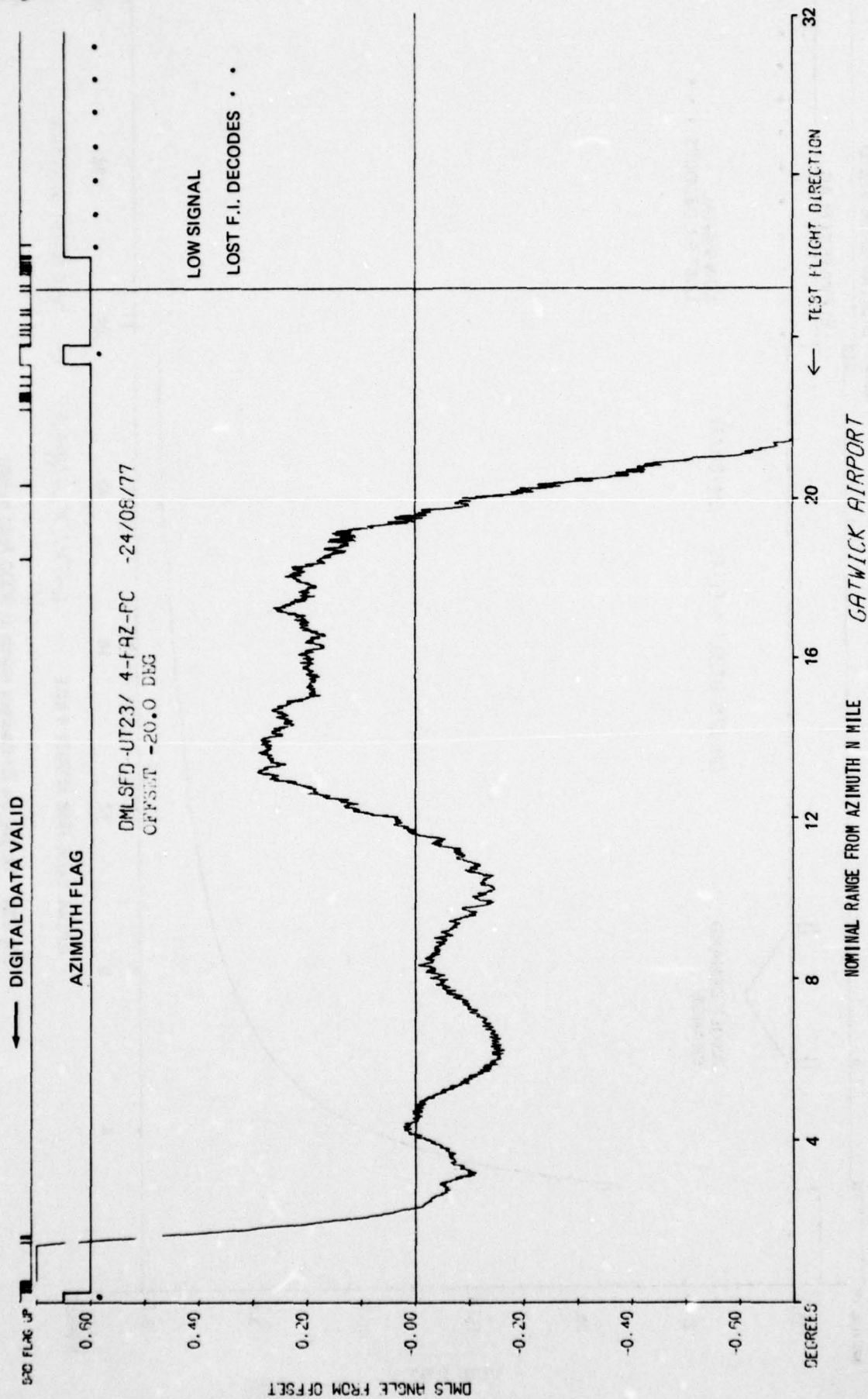


Fig 23b Radial on 20 degrees north at 3000 foot height

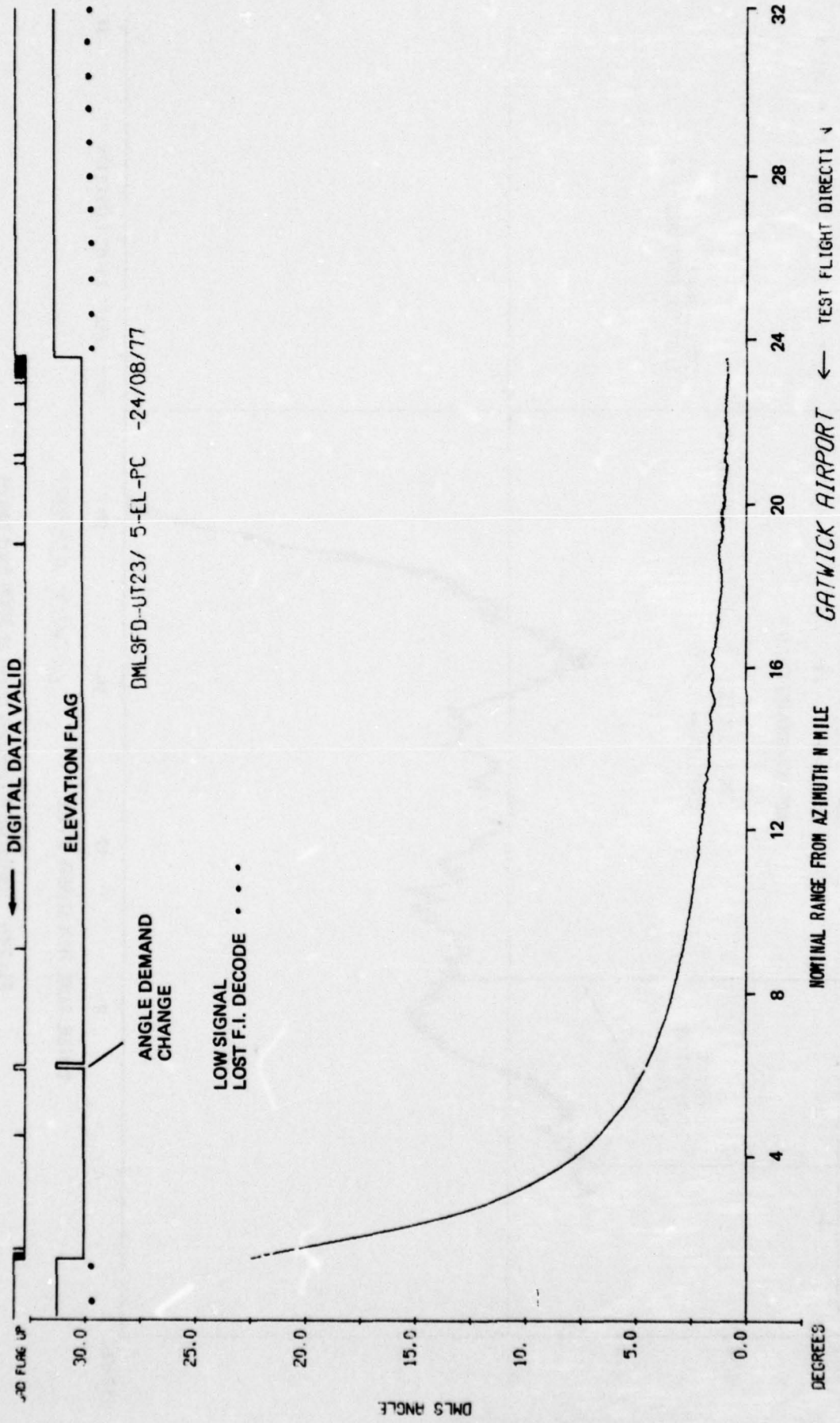


Fig 24a

Fig 24a Radial on 40 degrees north at 3000 foot height

Fig 24b

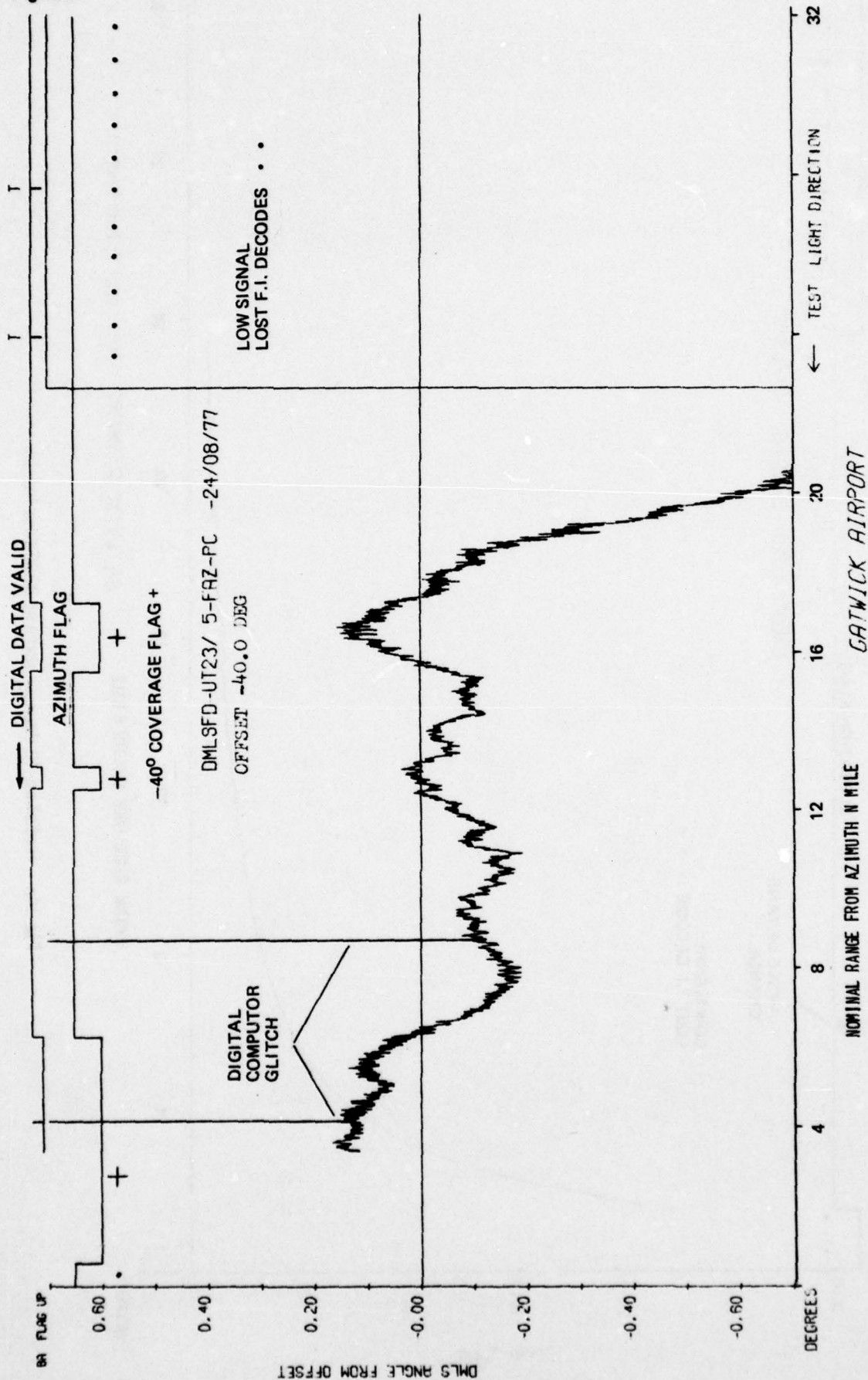


Fig 24b Radial on 40 degrees north at 3000 foot height

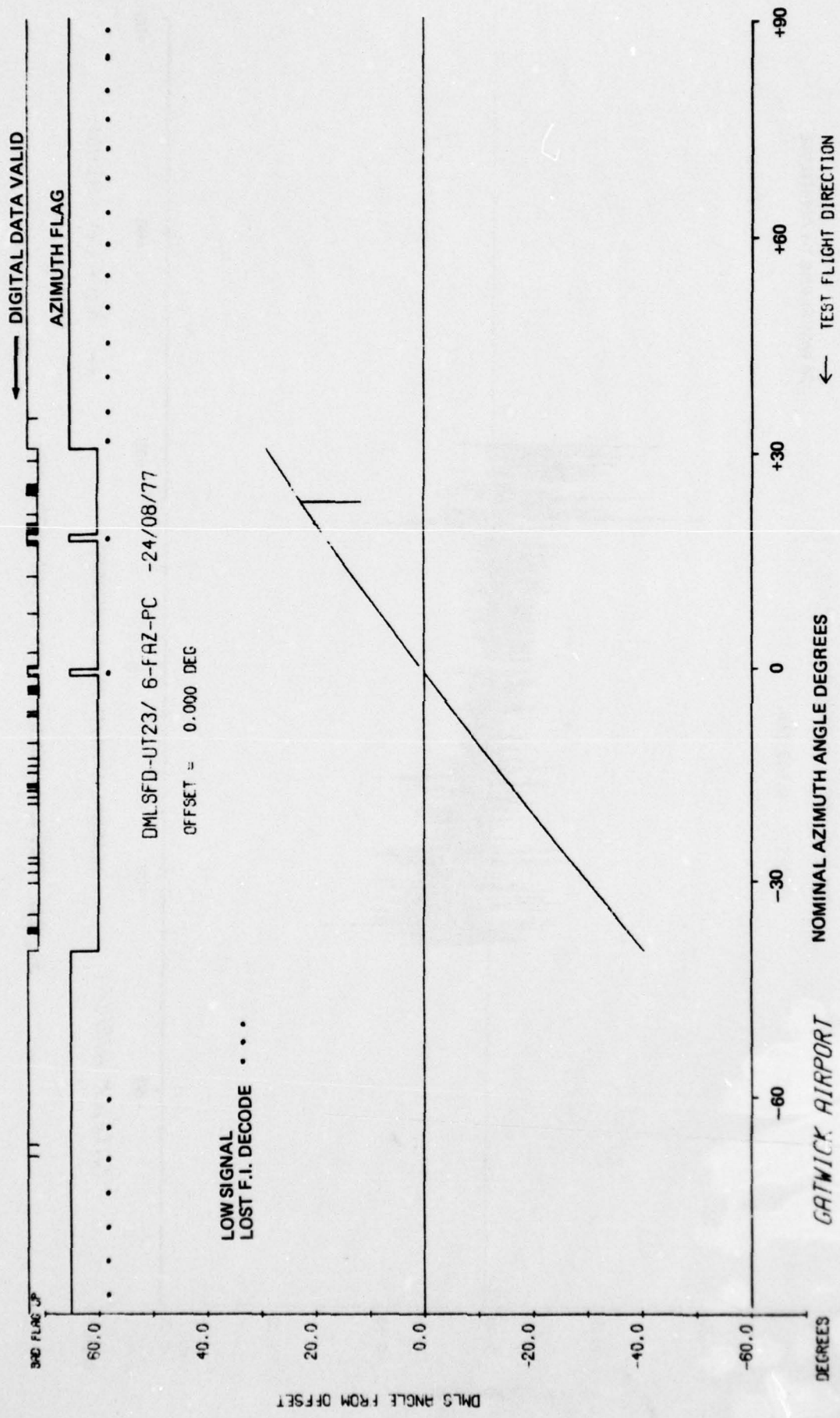


Fig 25a

Fig 25a 2500 foot orbit from south to north at 20 n mile

Fig 25b

FILTERED FOR
CONTROL MOTION NOISE

CENSORED
SND FLAG UP

DMLSFD-UT23/ 6-FAZ-PC -24/08/77

OFFSET = 0.000 DEG

54 WAVELENGTH APERTURE

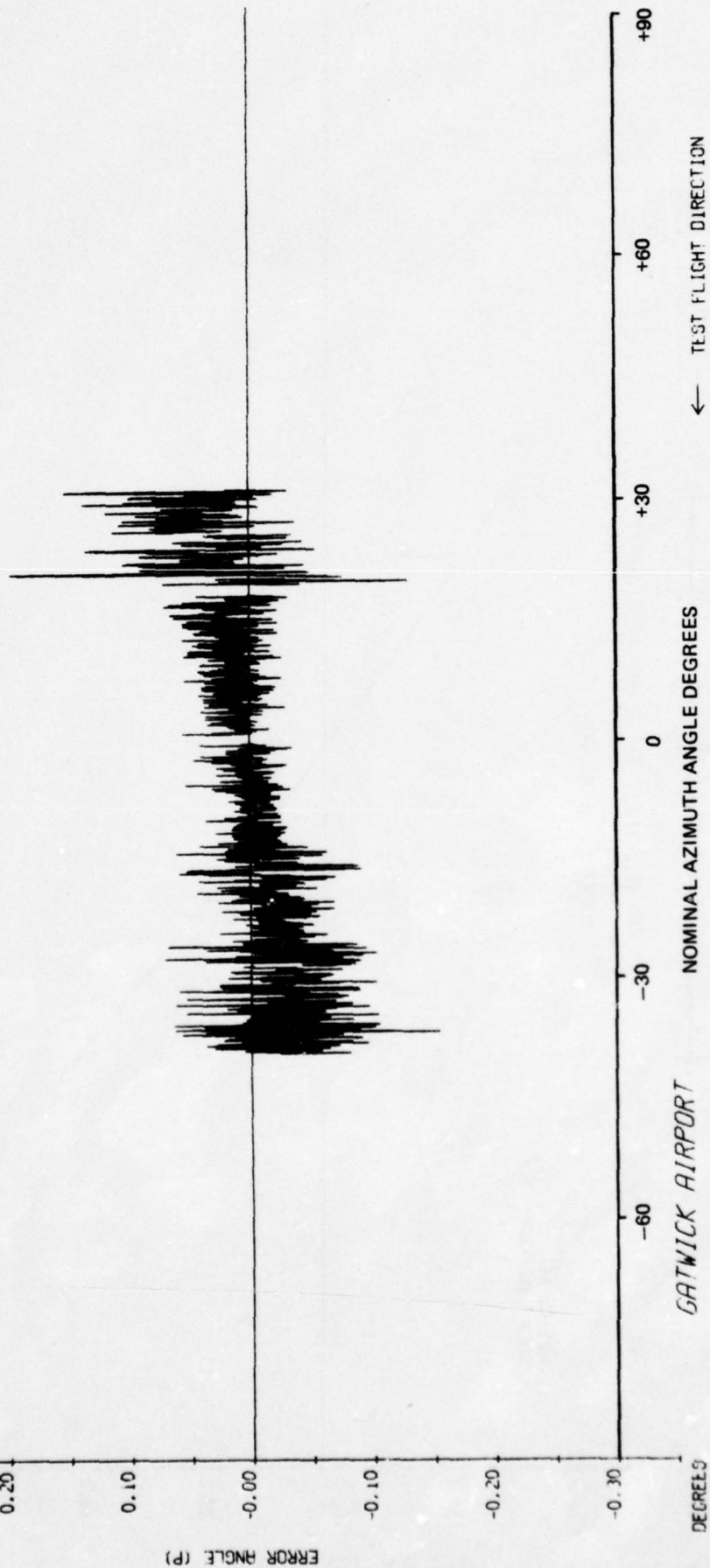


Fig 25b 2500 foot orbit from south to north at 20 n mile

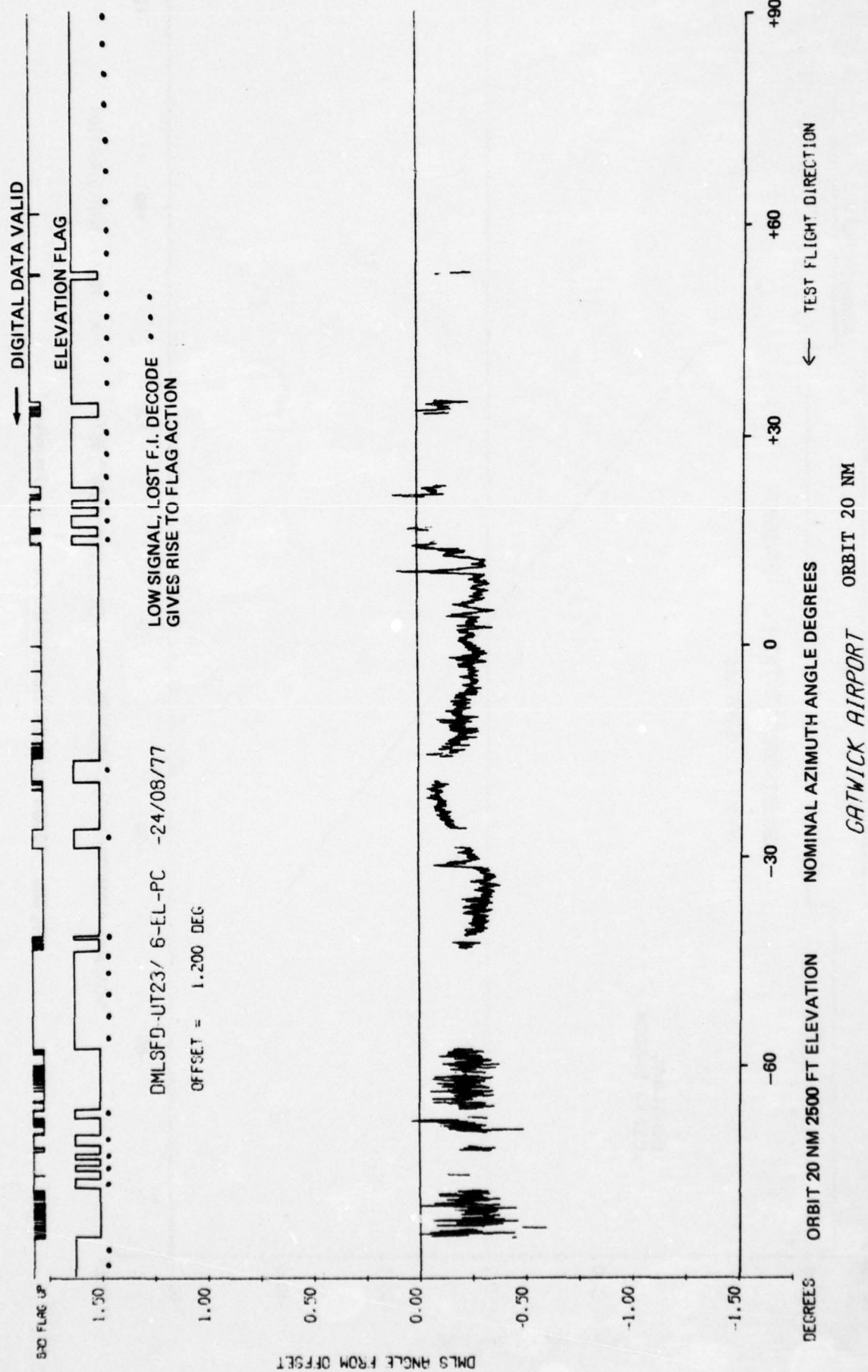


Fig 25c

Fig 25c 2500 foot orbit from south to north at 20 n mile

Fig 26a

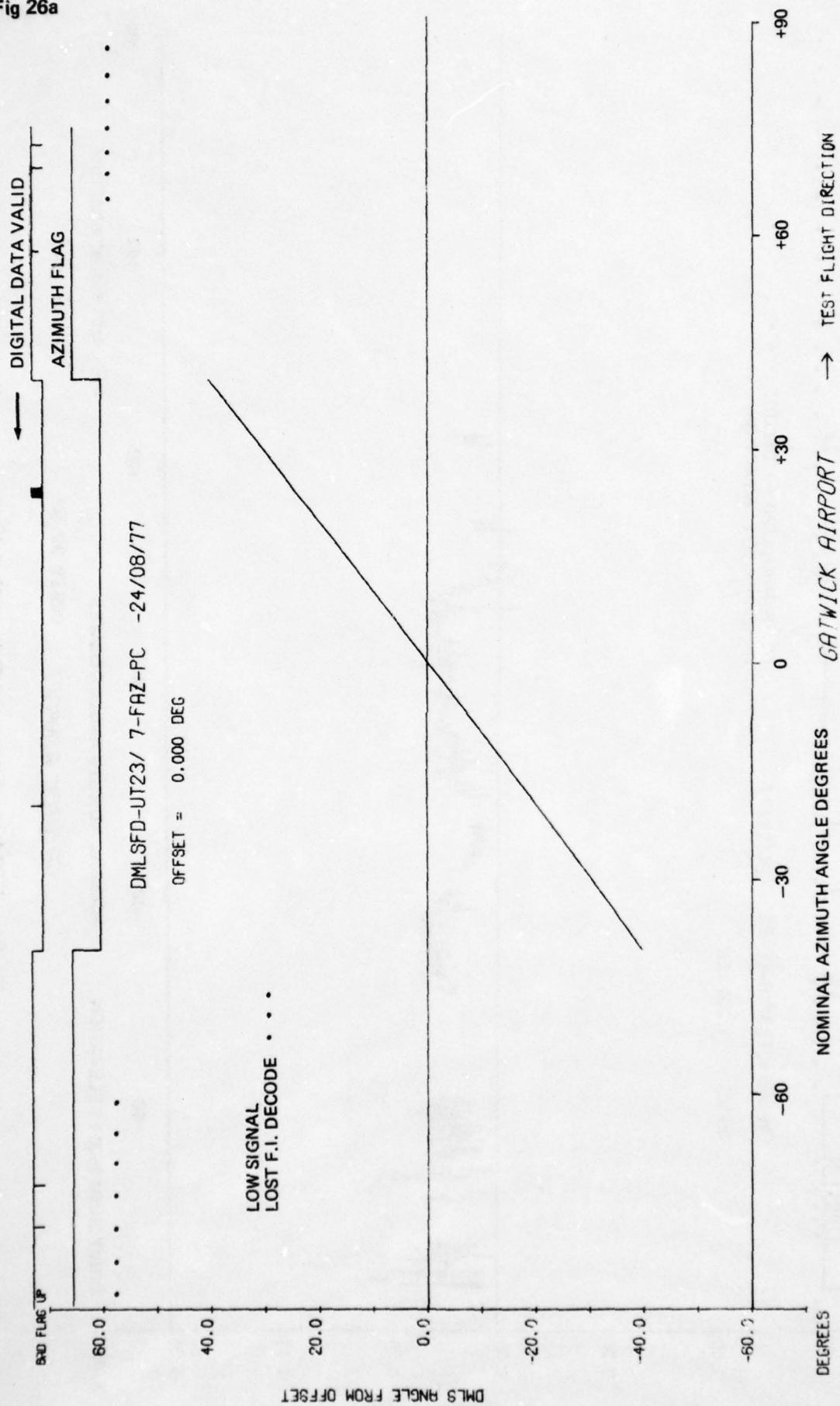


Fig 26a 10000 foot orbit from north to south at 20 n mile

CENSURED
BAD FLAG UP

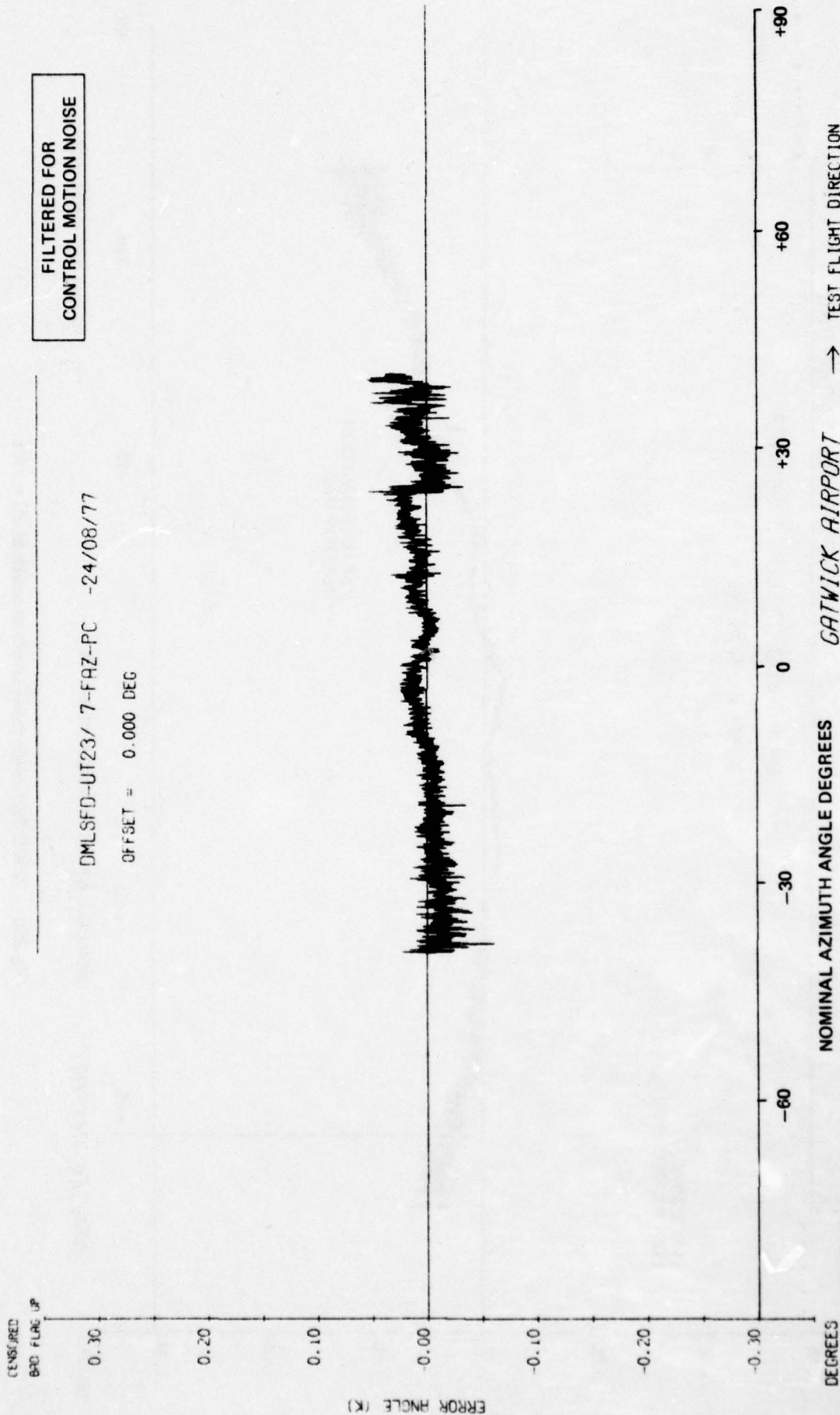


Fig 26b

Fig 26b 10000 foot orbit from north to south at 20 n mile

Fig 26c

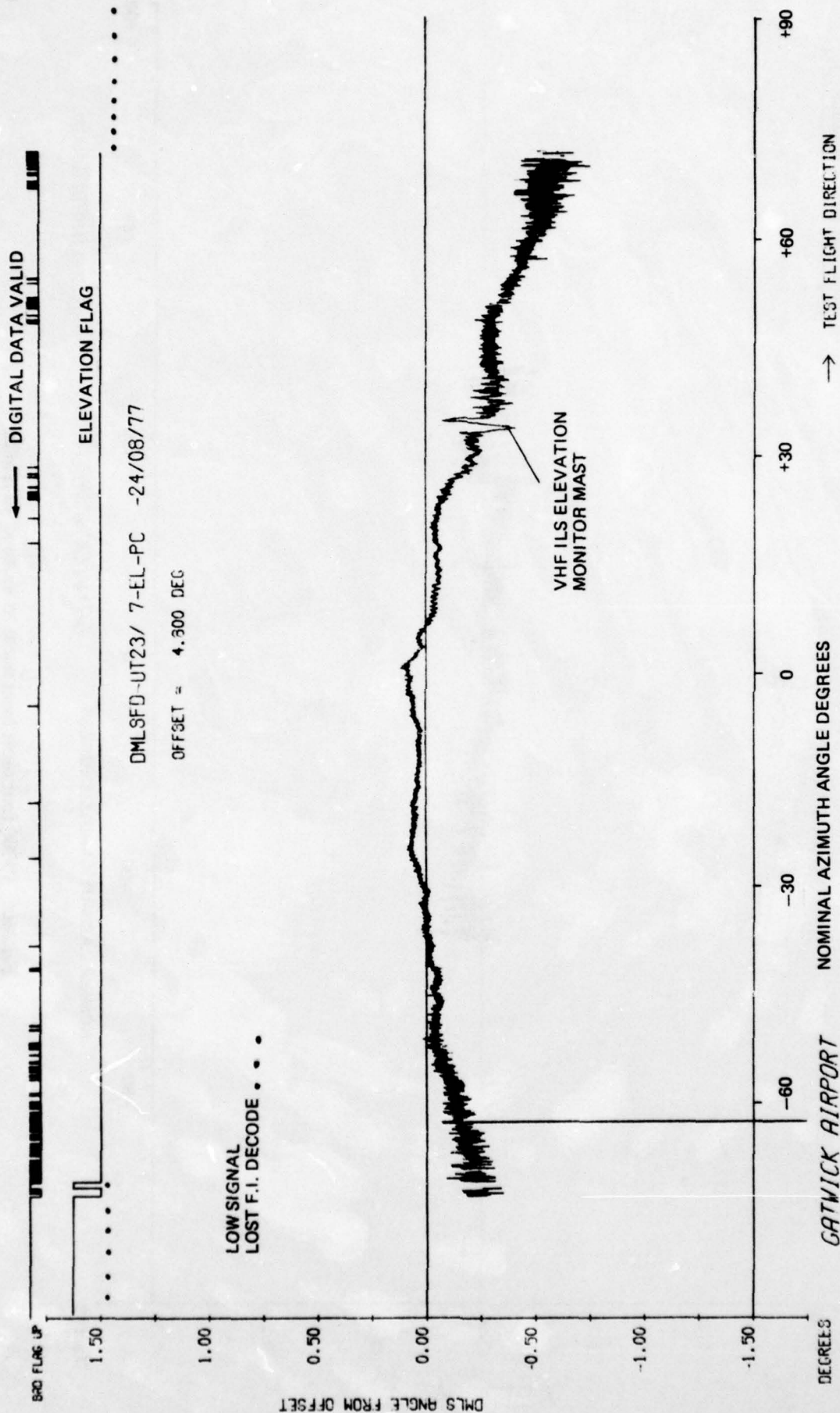


Fig 26c 10000 foot orbit from north to south at 20 n mile

Fig 27

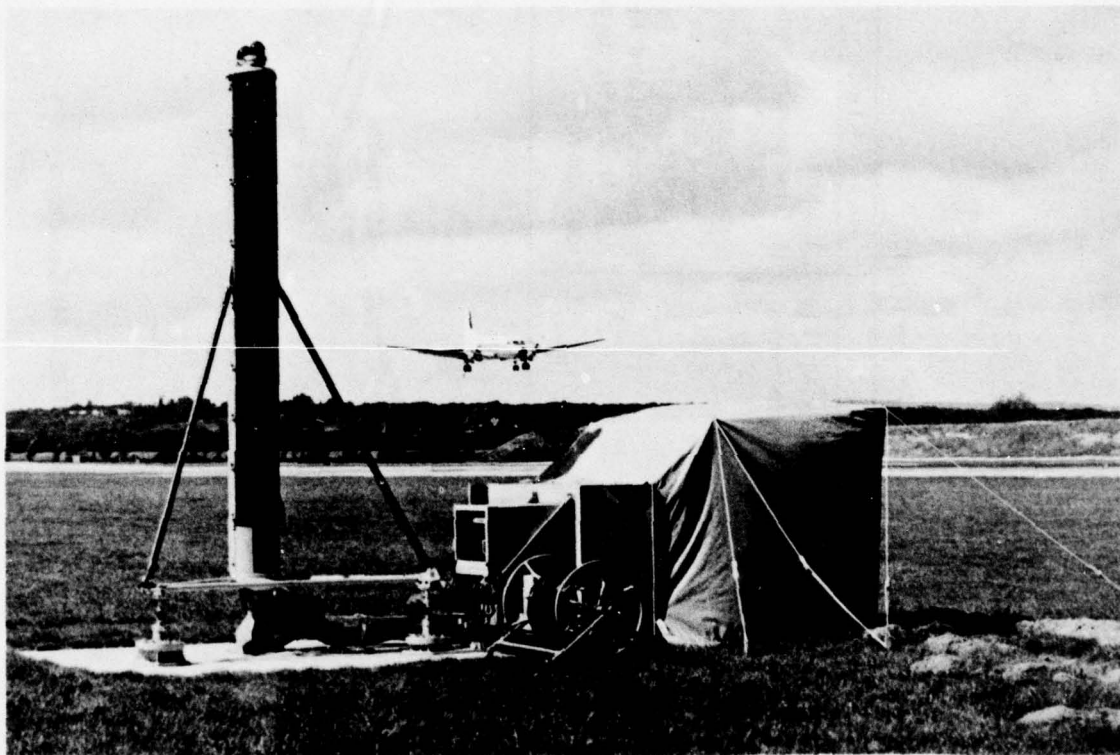


Fig 27 RAE Bedford HS 748 autolanding at Gatwick

Fig 28

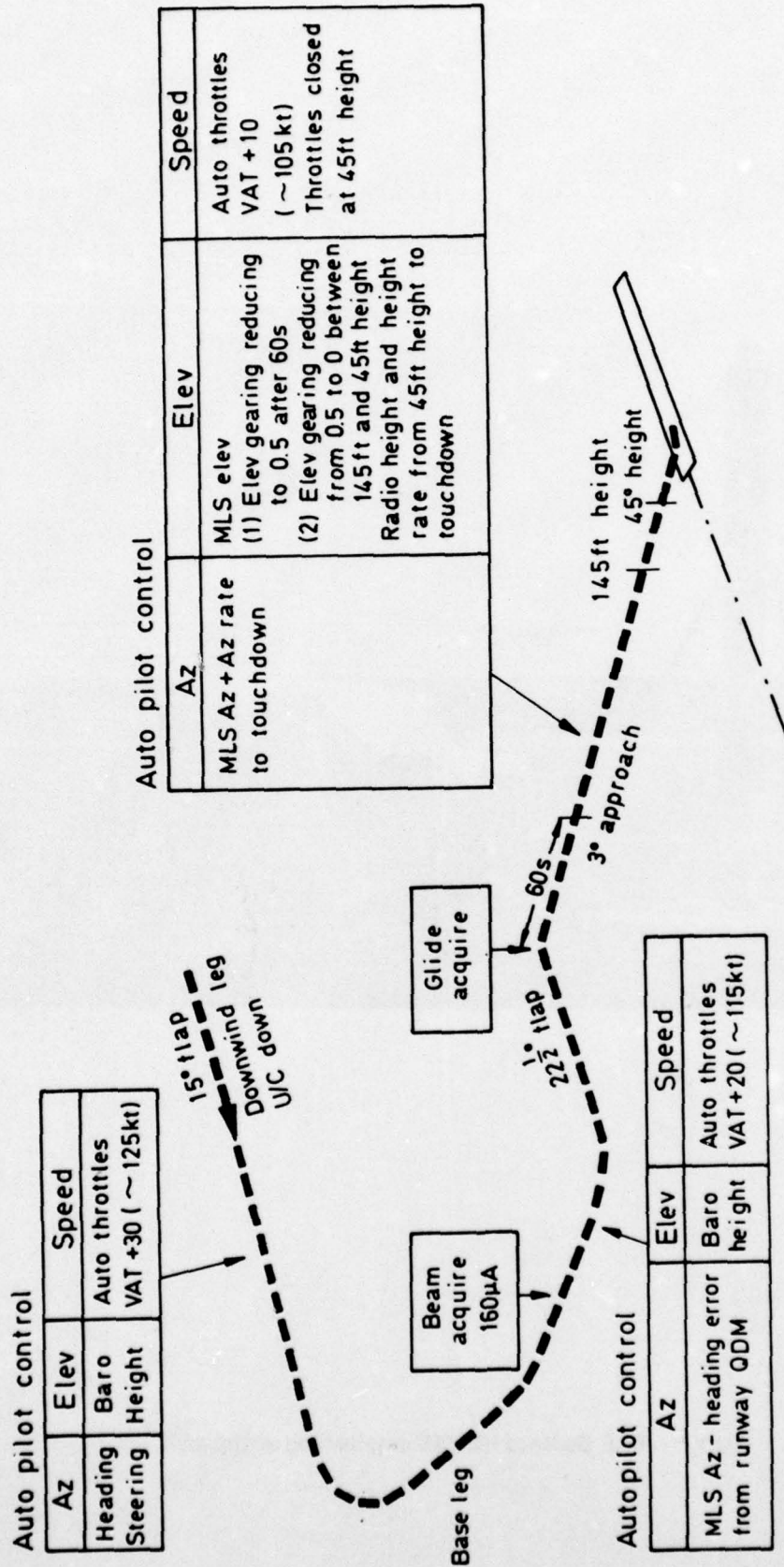


Fig 28 Typical circuit pattern for HS 748 - MLS guidance

Fig 29

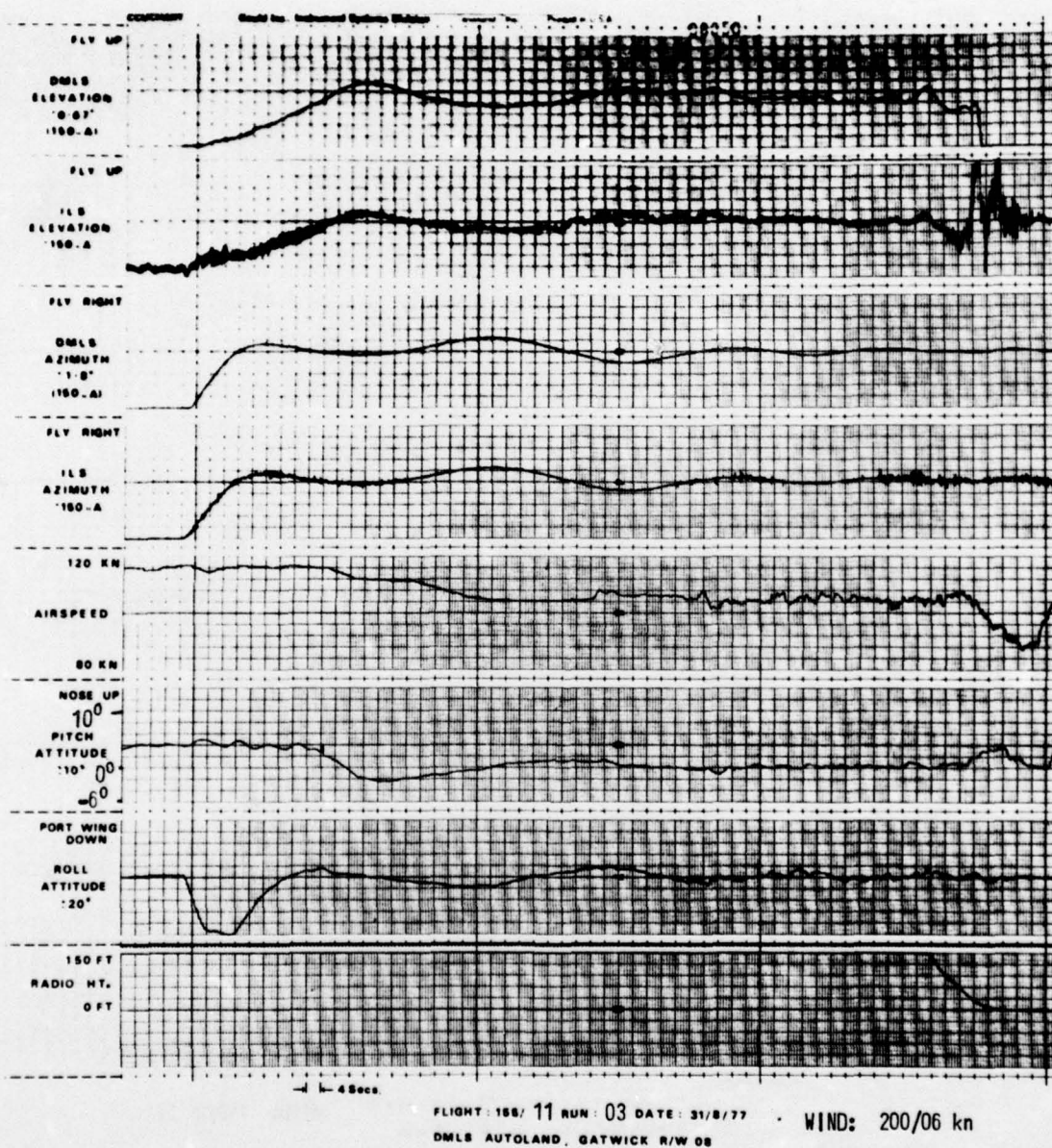


Fig 29 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 30

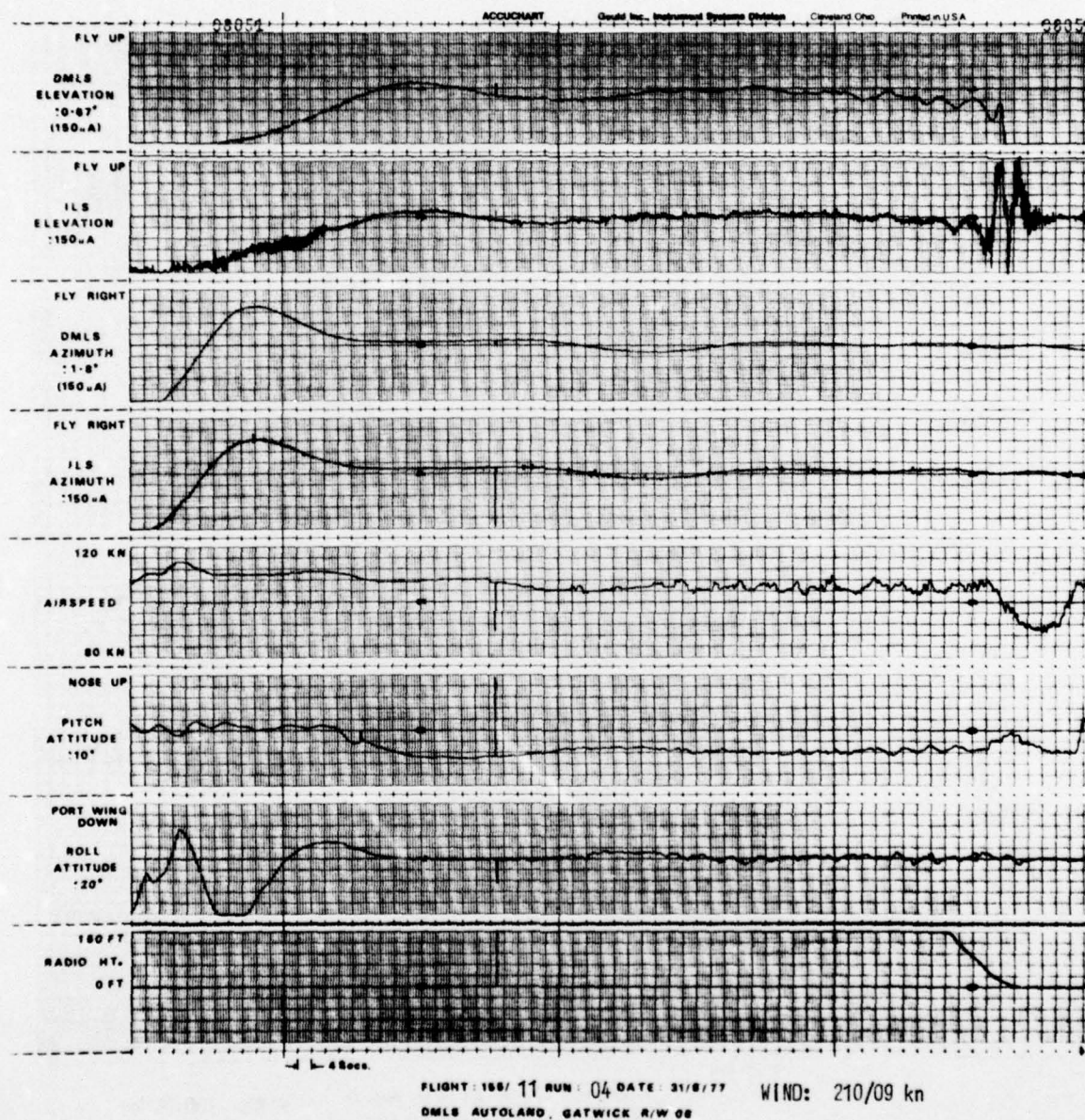


Fig 30 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 31

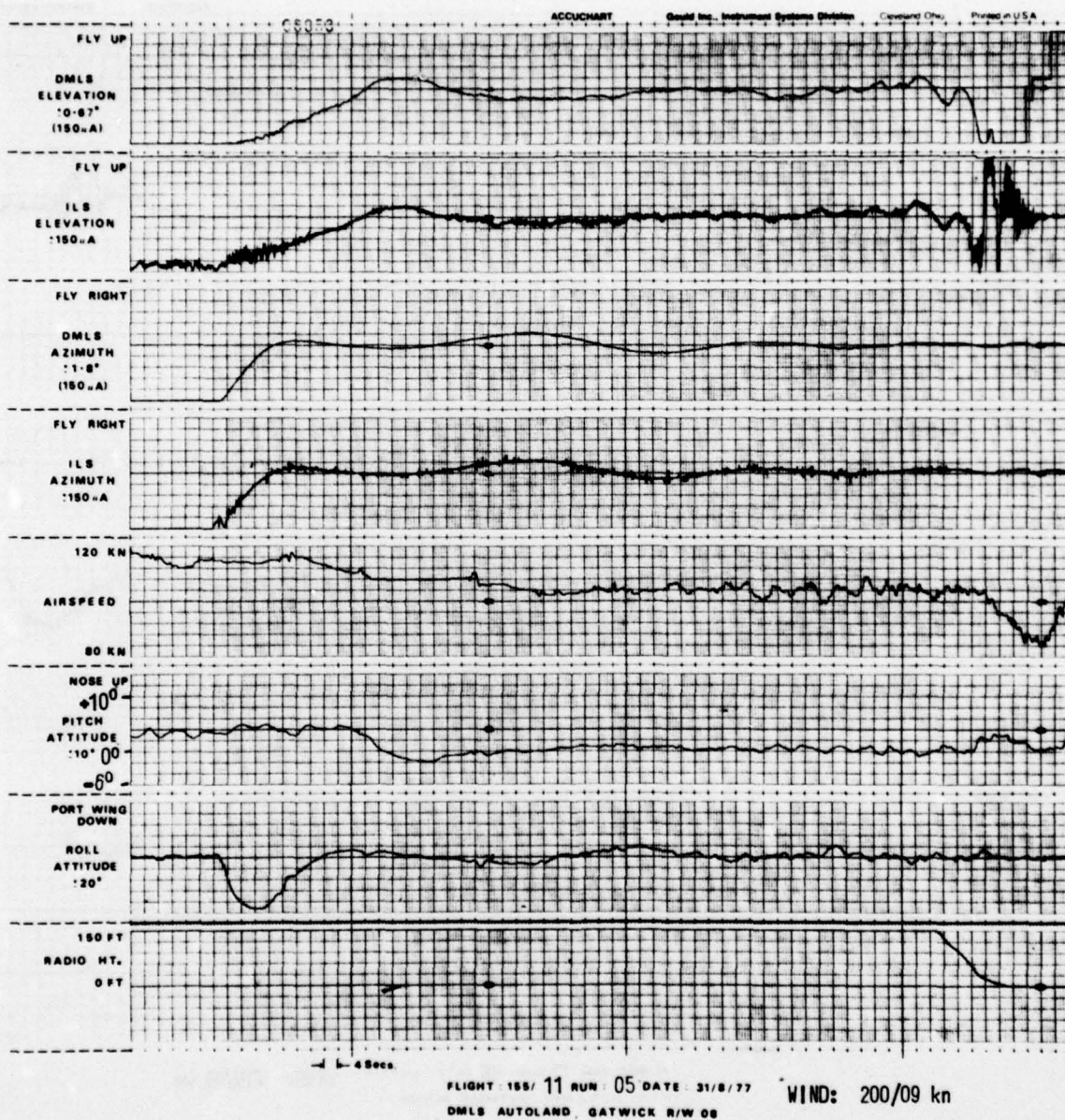


Fig 31 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 32

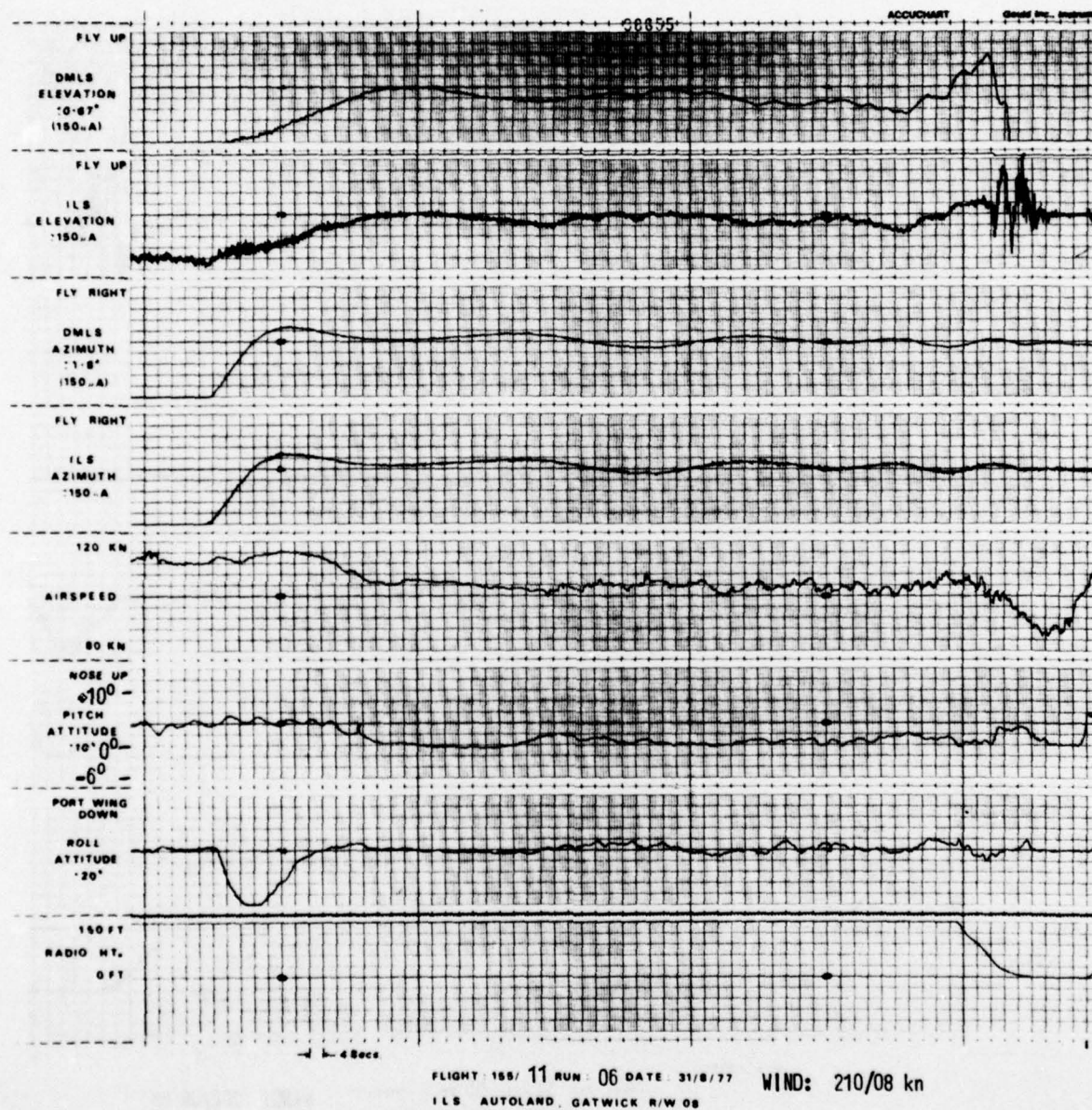


Fig 32 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 33

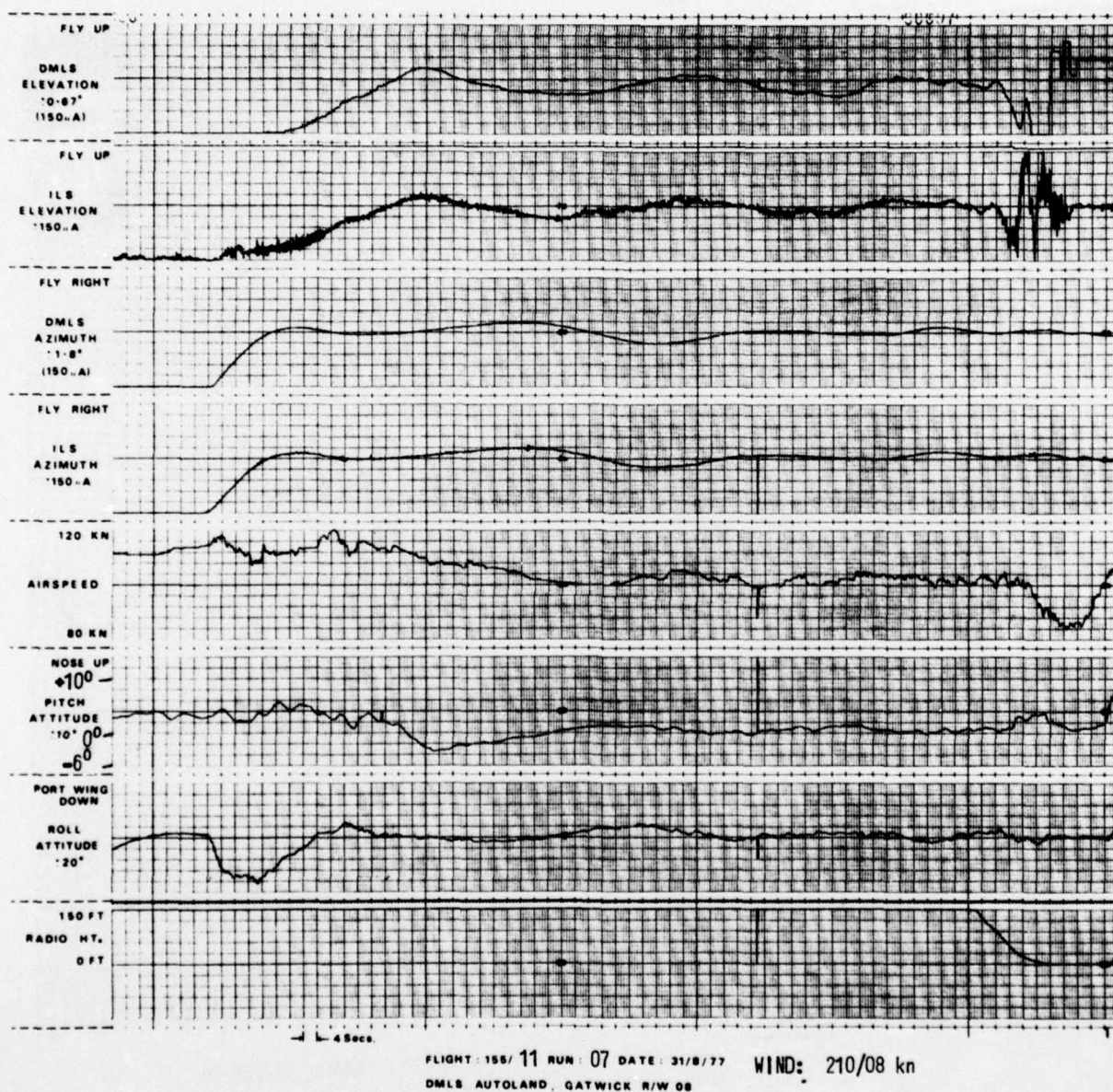


Fig 33 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 34

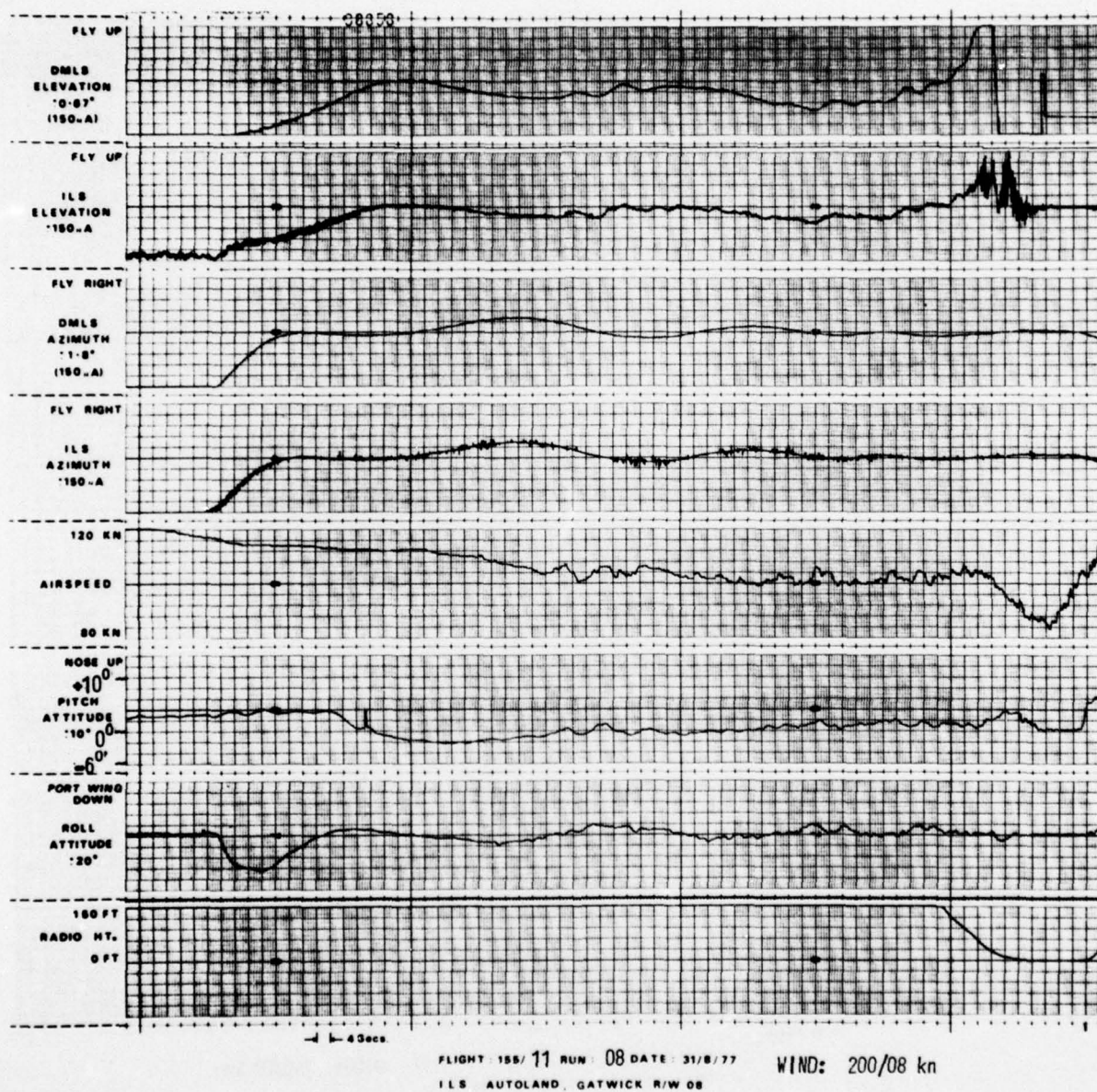


Fig 34 ILS autoland on runway 08 at Gatwick on 31.8.77

Fig 35

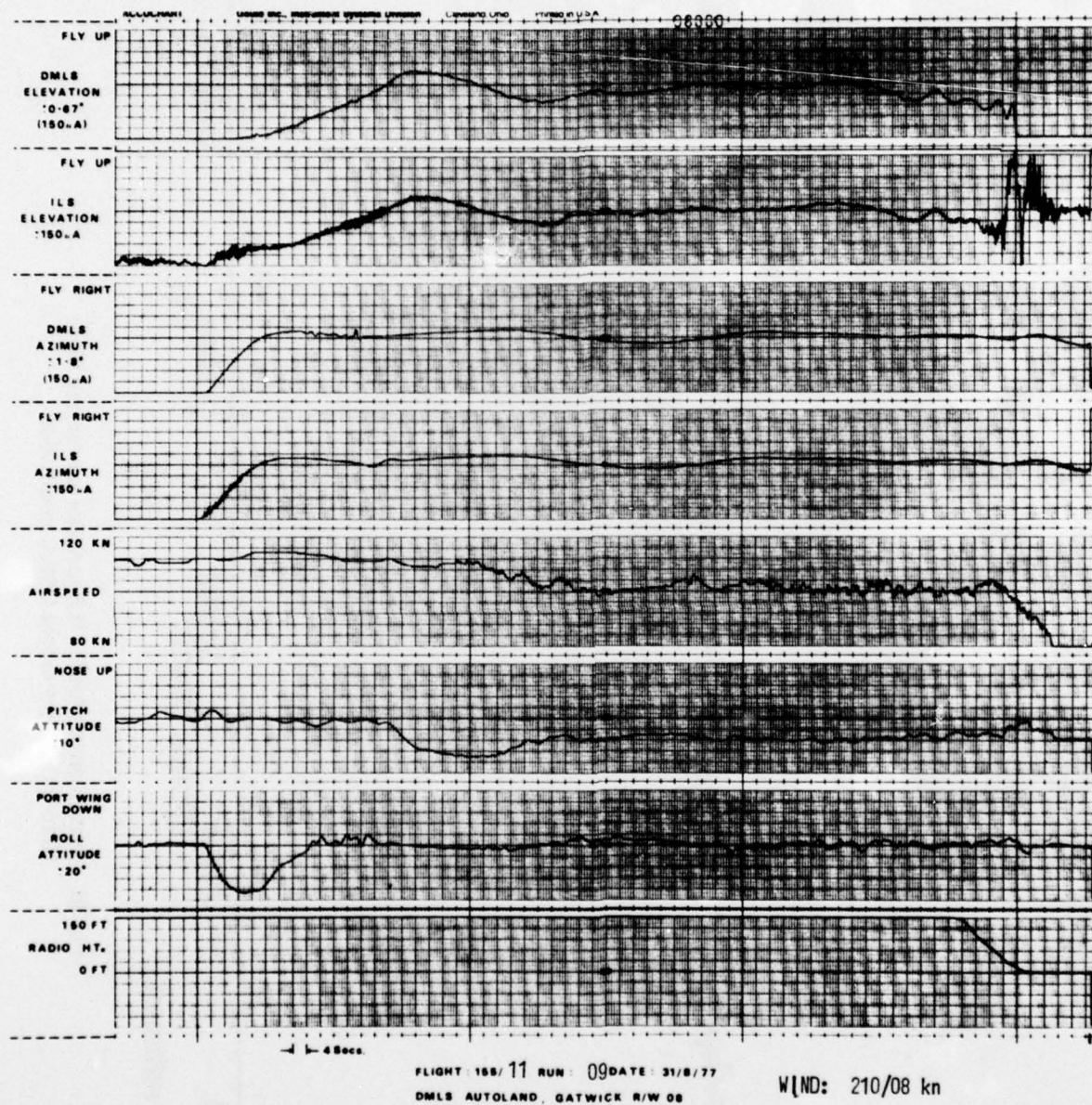


Fig 35 DMLS autoland on runway 08 at Gatwick on 31.8.77

Fig 36

DMLS-AH-17/01-LOC-ILS -11/8/77
GATWICK R/W 08

TRANSMITTER : ILS LOC PRE MLS
OFFSET : 0 DEGS

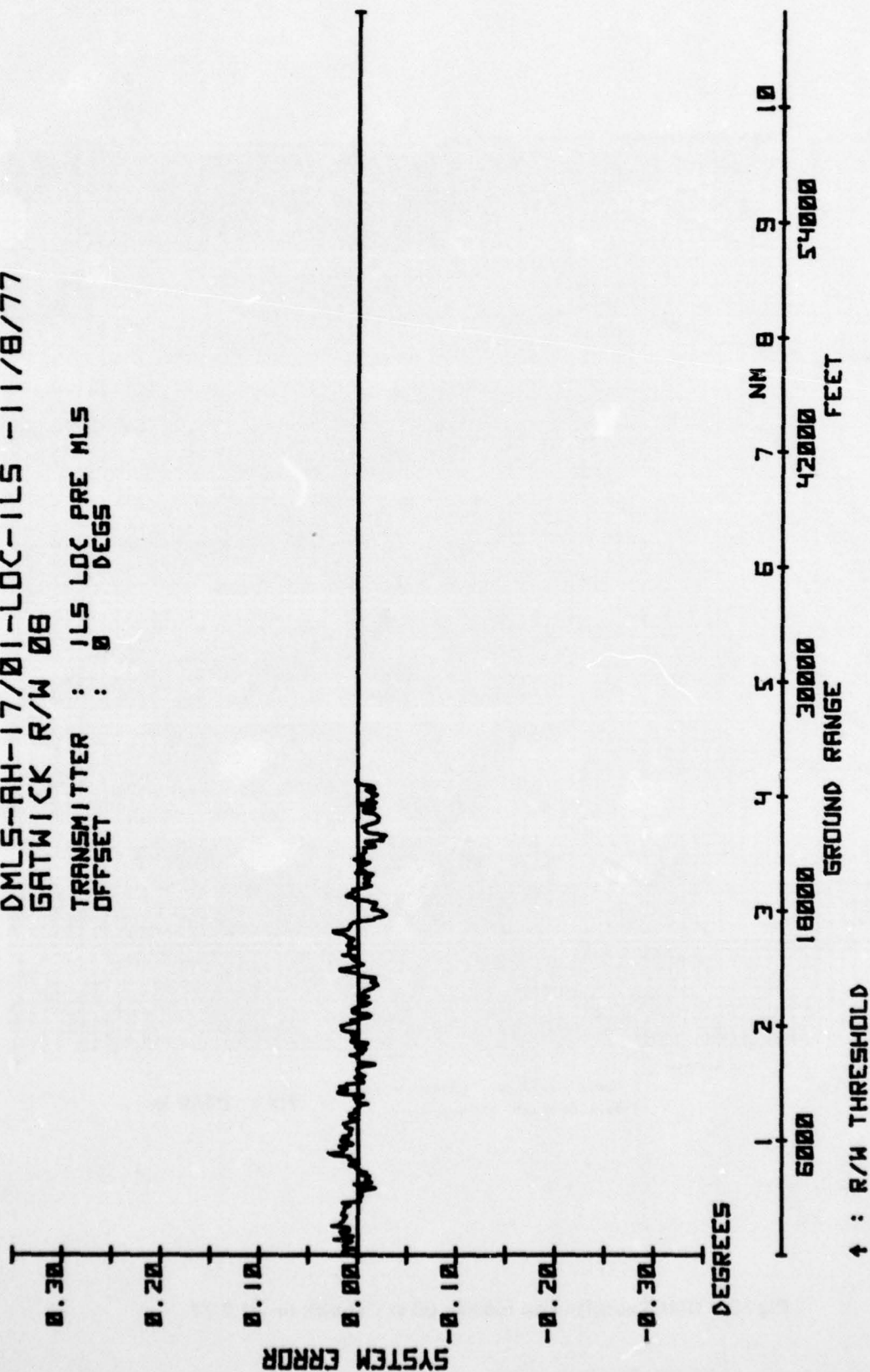


Fig 36 System error plot for ILS localizer on runway 08 at Gatwick Airport before DMLS installation

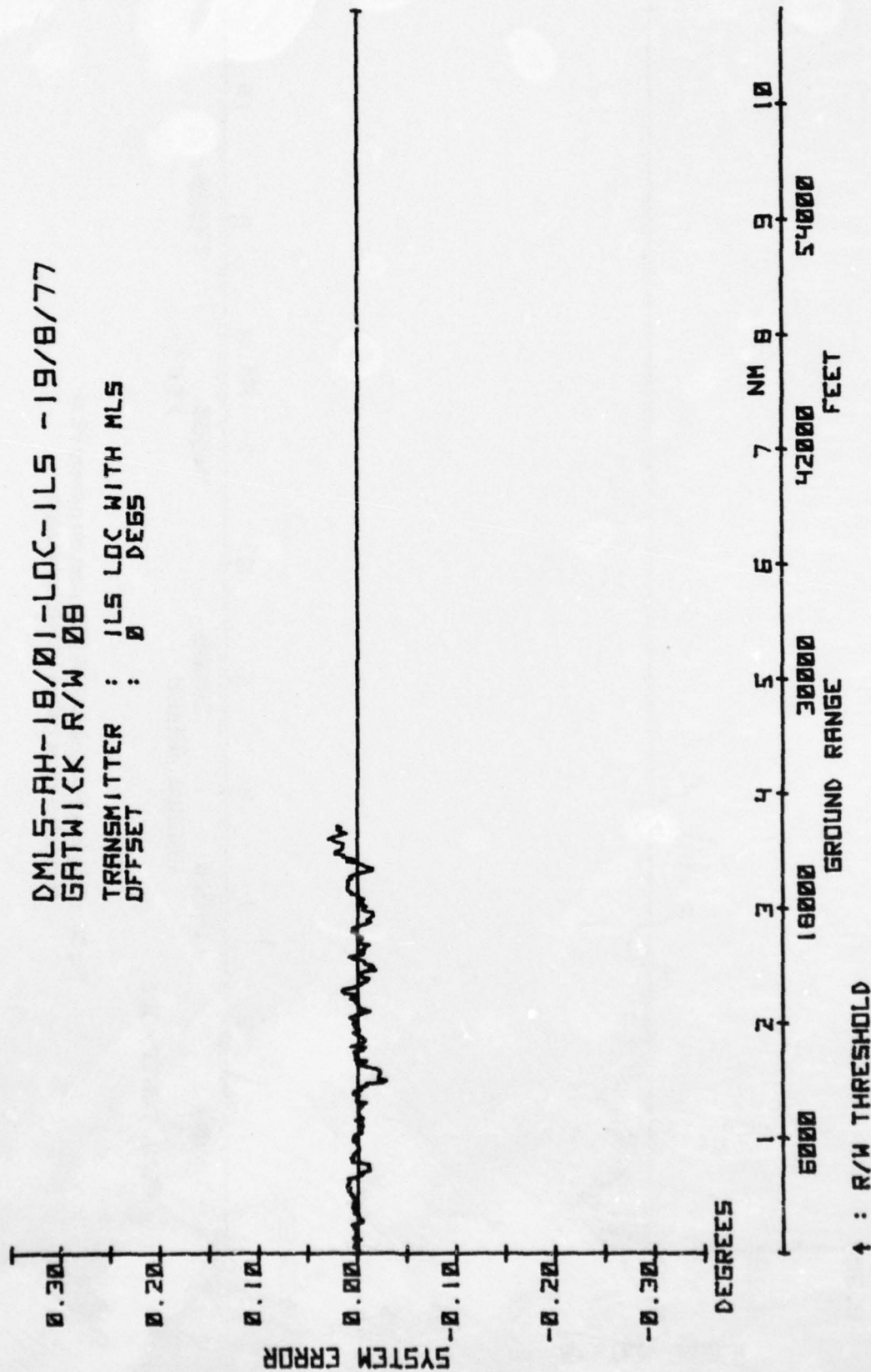


Fig 37 System error plot for ILS localizer on runway 08 at Gatwick Airport after DMLS installation

Fig 38

DMLS-AH-24/01-G.P-ILS -11/8/77

GATWICK R/W 08

TRANSMITTER : ILS G/P PRE MLS
OFFSET : 3 DEGS

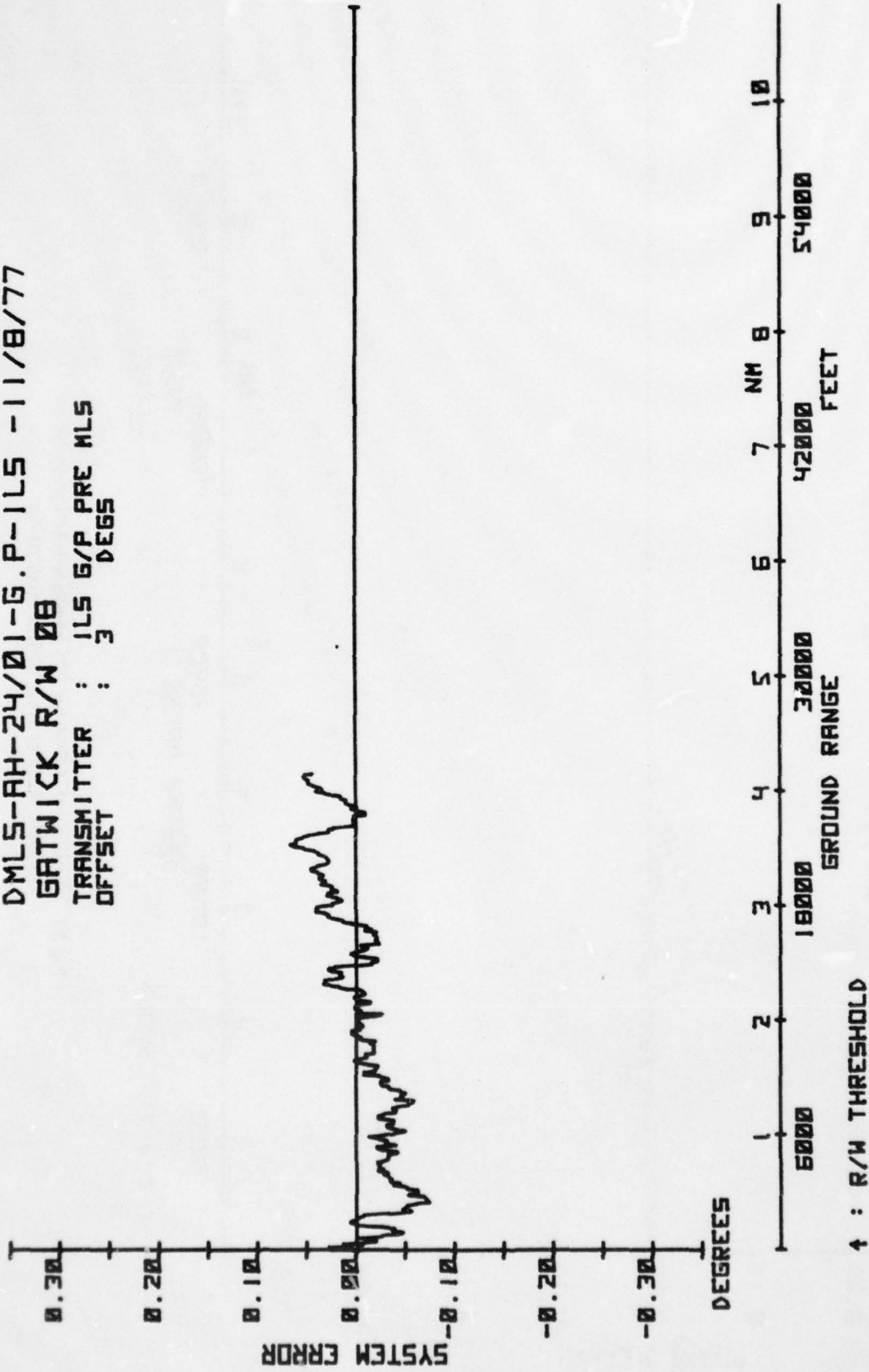


Fig 38 System error plot for ILS glide path on runway 08 at Gatwick Airport before DMLS installation

DMLS-AH-25/01-G.P-ILS -23/8/77
 GATWICK R/W 08
 TRANSMITTER : ILS G/P WITH MLS
 OFFSET : 3 DEGS

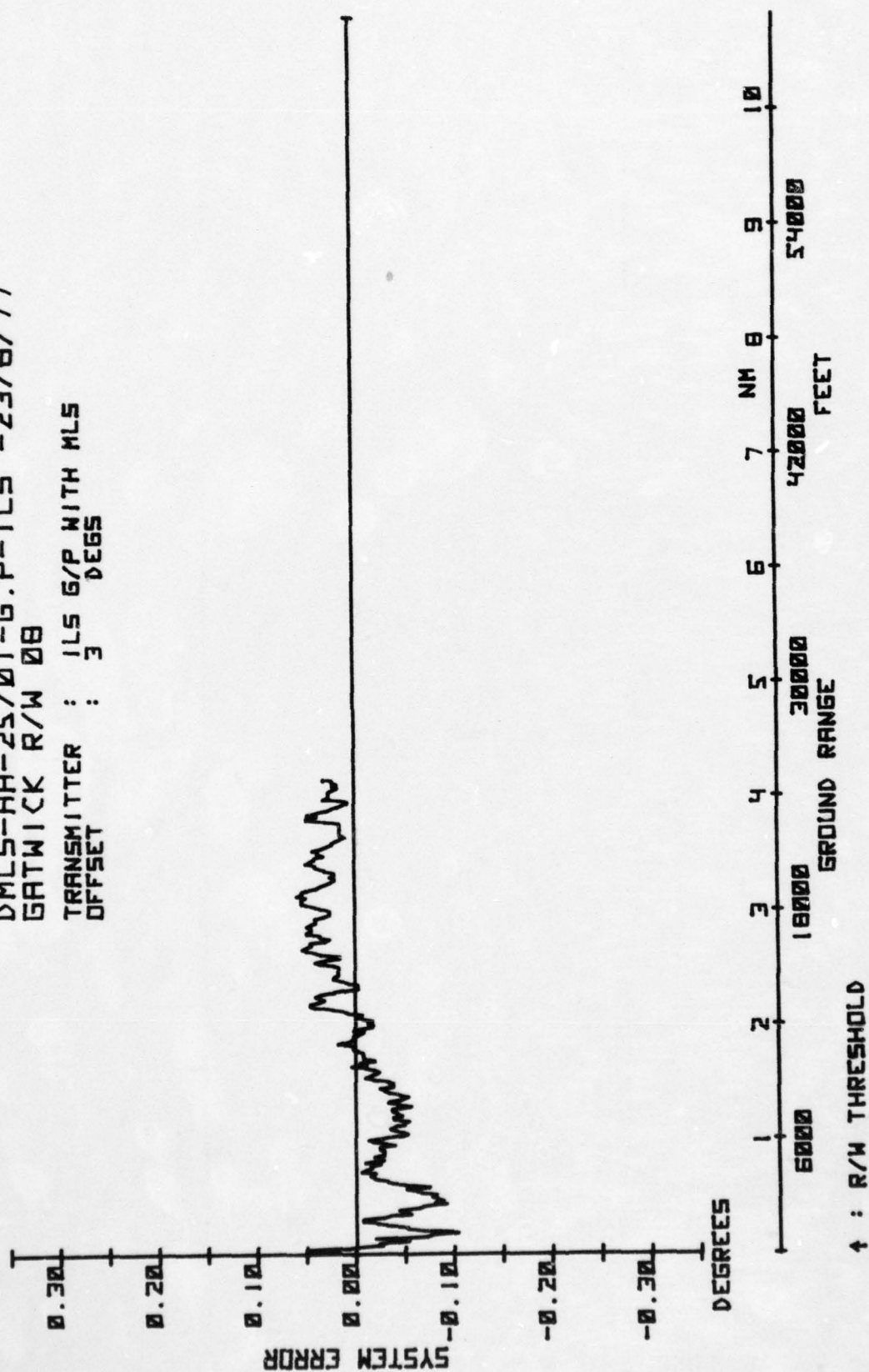


Fig 39 System error plot for ILS glide path on runway 08 at Gatwick Airport after DMLS installation